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## The use of scaffolding to improve student learning with interactive multimedia programs in chemistry

Brian T. Grimes  
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**The Use of Scaffolding to Improve Student Learning  
with Interactive Multimedia Programs in Chemistry**

**B.T. Grimes  
2002  
M.Ed**

# **The Use of Scaffolding to Improve Student Learning with Interactive Multimedia Programs in Chemistry**

**Brian T. Grimes B.Sc, Dip. Ed, MRACI, C.CHEM**

A thesis submitted in partial fulfilment  
of the requirements for the award of  
**Master of Education**  
at the Faculty of Community Services, Education and Social Science, Edith  
Cowan University.

**August, 2002.**

## ABSTRACT

The process of balancing and interpreting chemical equations involves the consideration of an abstract, non-observable phenomenon coupled with multi-level representation. Students find it conceptually demanding to visualise the particulate level of matter and hence experience difficulty in balancing chemical equations with understanding.

Interactive multimedia with dynamic computer graphics can provide students with accurate, concrete representations of the particulate nature of matter. Such tools, when coupled with appropriate implementation strategies, have the potential to improve learning about chemical reactions.

The study investigated the use of scaffolding techniques to enhance and direct student learning when using an interactive multimedia software (IMM) program, *Balancing and Interpreting Chemical Equations* (Garnett, Hackling & Oliver, 1997a) designed to develop skills and understanding of balancing and interpreting chemical equations.

This research was conducted as an interpretive, collective case study which was supplemented with data from pre and posttests. In this design, a total of 12 Year 10 students were selected by purposeful sampling, arranged in pairs and then randomly assigned to either using the specified IMM software with or without scaffolding. Students were observed by the researcher whilst using the IMM software and various student interactions were recorded by a variety of media, including screen-capture of their interactions with the IMM software, audio recordings of the interactions and collaborations between students in pairs, and videotape recordings of both the interactions and collaborations between students in pairs and between students and the IMM software. The data from these sources, in addition to data from the pre and posttests, was used to generate a case history file which was analysed to elucidate information about how scaffolding affects the way in which students interact with the IMM software; how scaffolding affects the way in which students interact and collaborate with each other whilst working on the IMM software; and whether there was any evidence of enhanced understanding of the particulate nature of reactions and

success in writing and balancing chemical equations following the use of this IMM software with scaffolding.

The research indicated that scaffolding affects the manner in which students interact with the IMM software by encouraging and directing more efficient and deliberate access to the salient features of the program at specific times in the learning sequence. The research also indicated that the level of collaboration between students working in dyads on the IMM software was influenced by the use of the scaffolds and that once applied, the fading of support in scaffolded worksheets did not result in a deterioration of the nature or extent of the interactions within the dyad. Finally, while the scaffolds did not always result in higher levels of cognitive achievement (compared to non-scaffolded instruction), they did enhance the IMM learning environment and the opportunity for conceptual change.

The implications that arise from this research extend to the use of this IMM software in the classroom, teaching practices within an IMM environment, software designers, and for further research.

## DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

- (i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;
- (ii) contain any material previously published or written by another person except where due reference is made in the text; or
- (iii) contain any defamatory material.

Signed:

 Brian Grimes



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**B Grimes**

## TABLE OF CONTENTS

CHAPTER		PAGE
ABSTRACT		ii
DECLARATION		iv
ACKNOWLEDGEMENTS		v
TABLE OF CONTENTS		vi
LIST OF FIGURES		ix
LIST OF TABLES		xiv
1	INTRODUCTION	1
	Introduction	1
	The Problem	3
	Rationale and Significance	4
	Research Questions	7
2	LITERATURE REVIEW	8
	Learning and Conceptual Change	8
	Learning	8
	Information processing model of cognition	9
	A holistic approach to memory	11
	Memory structures and elements	13
	Constructivism	16
	Role of prior knowledge	16
	Language and social factors	17
	Cognitive Apprenticeship Model of Instruction	18
	Scaffolded Instruction and IMM	21
	Learning with IMM	22
3	METHODOLOGY AND DATA COLLECTION	31
	Design	31
	The Program	32

	The Participants	34
	The researcher	34
	Student participants	34
	Pilot Study	35
	Procedure	35
	Instruments	38
	Scaffolded guides	38
	Pretest and posttests	38
	Interviews	39
	Data Analysis	39
	Limitations of the Research	42
4	RESULTS AND DISCUSSION: STUDENTS' UNDERSTANDING OF THE PARTICULATE NATURE OF MATTER	44
	Knowledge of Symbols, Chemical Formulae and the Meaning of Coefficients	44
	Discussion and assertions	52
	Representations of the Particulate Nature of Matter	56
	Discussion and assertions	61
	Balancing Chemical Equations	64
	Discussion and assertions	73
	Chapter Summary	76
5	RESULTS AND DISCUSSION: STUDENTS' UNDERSTANDING OF THE REACTION PROCESS	78
	Students' Understanding of Stoichiometric Relationships	78
	Discussion and assertions	81
	Students' Understanding of Limiting Reagents	84
	Discussion and assertions	91
	Writing Balanced Equations from Pictorial Representations	94
	Discussion and assertions	98
	Chapter Summary	101

6	RESULTS AND DISCUSSION: STUDENTS' INTERACTION WITH THE IMM SOFTWARE	103
	Learner Control and the Sequence of Instructional Paths	103
	Discussion and assertions	112
	Learner Control	117
	Discussion and assertions	121
	Instructional Time	123
	Discussion, assertions and observations	124
	Chapter Summary	125
7	RESULTS AND DISCUSSION: STUDENT INTERACTION AND COLLABORATION WHILST USING THE IMM SOFTWARE	127
	Student Interaction and Collaboration whilst Using the IMM Software	127
	Peer Conflict and Co-construction of Knowledge	147
	Discussion, assertions and observations	153
	Chapter Summary	162
8	GENERAL DISCUSSION, CONCLUSIONS AND IMPLICATIONS	164
	Implications for Teaching	178
	Implications for Software Design	180
	Implications for Further Research	183
	REFERENCES	185
	APPENDICES	
1	PROGRAM DESCRIPTION	197
2	PRETEST/ POSTTEST	204
3	SCAFFOLDED GUIDES	215
4	DEVELOPMENT OF GENERAL ASSERTIONS	225
5	DEVELOPMENT OF CONCLUSIONS	239

## LIST OF FIGURES

Number		Page
2-1	The three memory structures involved in processing input and their interconnections	9
2-2	Diagram illustrating a proposed model of how learning is dismembered and remembered	12
2-3	Diagram illustrating the interrelationships of memory structures and performance outcomes	15
2-4	The interaction that exist with an IMM environment	26
3-1	Methodology used for research into the use of scaffolding to improve student learning with interactive multimedia programs in chemistry	37
3-2	The relationship between the research questions, data sources and methods of analysis	41
4-1	Question 1 from pre and posttests	45
4-2	Pretest interview A with Student 7	46
4-3	Pretest interview A with Student 10	47
4-4	Posttest interview A with Student 7	48
4-5	Posttest interview A with Student 10	48
4-6	Question 2 from pre and posttests	49
4-7	Work sample from Student 2 for Question 2	49
4-8	Pretest interview A with Student 2	50
4-9	Work sample from Student 5 for Question 2	50
4-10	Pretest interview A with Student 5	51
4-11	Work sample from Student 7 for Question 2	51
4-12	Pretest interview A with Student 3	57
4-13	Posttest interview A with Student 3	57

4-14	Pretest interview B with Student 5	57
4-15	Posttest interview A with Student 5	58
4-16	Pretest interview A with Student 8	58
4-17	Posttest interview A with Student 2	59
4-18	Posttest interview B with Student 5	60
4-19	Posttest interview B with Student 10	60
4-20	Question 3 from pre and posttests	64
4-21	Work sample from Student 7 for Question 3 (pretest)	66
4-22	Work sample from Student 7 for Question 3 (posttest)	66
4-23	Pretest interview B with Student 7	67
4-24	Posttest interview B with Student 7	67
4-25	Questions 4 and 5 from pre and posttests	68
4-26	Work samples from Students 2 and 9 for Question 5	69
4-27	Posttest interview A with Student 8	69
4-28	Work samples from Students 2, 4, 6 and 8 for Question 5	71
4-29	Posttest interview B with Student 8	72
4-30	Excerpt from an audio recording of Student 2	72
4-31	Work sample from Student 4 for Question 3	73
5-1	Questions 6 - 9 from pre and posttests	79
5-2	Pretest interview A with Student 6	81
5-3	Question 10 from pre and posttests	84
5-4	Question 11 from pre and posttests	85
5-5	Pretest interview B with Student 8	87
5-6	Pretest interview C with Student 8	87
5-7	Interaction sequence A within Dyad 5	90

5-8	Question 12a from pre and posttests	94
5-9	Question 12b from pre and posttests	95
5-10	Question 12c from pre and posttests	95
6-1	Interview A with Student 1	106
6-2	Interview A with Student 12	107
6-3	Interview A with Student 9	108
6-4	Interaction sequence A within Dyad 2	117
6-5	The percentage of time in which each student had control of the computer (learner control)	118
6-6	Interview A with Student 2	119
6-7	Interview A with Student 3	119
6-8	Interview A with Student 6	120
6-9	Interview A with Student 9	121
7-1	Interaction sequence A within Dyad 1	130
7-2	Interaction sequence B within Dyad 1	131
7-3	Interaction sequence C within Dyad 1	132
7-4	Interaction sequence B within Dyad 2	134
7-5	Interaction sequence C within Dyad 2	135
7-6	Interaction sequence A within Dyad 3	138
7-7	Interaction sequence A within Dyad 4	140
7-8	Interaction sequence B within Dyad 4	140
7-9	Interaction sequence C within Dyad 4	141
7-10	Interaction sequence B within Dyad 5	142
7-11	Interaction sequence C within Dyad 5	143
7-12	Interaction sequence A within Dyad 6	145
7-13	Interaction sequence B within Dyad 6	145

7-14	Interaction sequence C within Dyad 6	146
7-15	A social interaction between Students 10 and 12	151
7-16	A social interaction between Students 6 and 7 in which Student 7 exhibits low self-esteem and a lack of motivation	151
7-17	An interaction between Students 1 and 5 discussing the procedure to be followed	152
7-18	An interaction between Students 8 and 9 discussing the procedure to be followed	152
10-1	The title screen for the program <i>Balancing and Interpreting Chemical Equations</i>	199
10-2	The computer page displaying the three available modules in the program <i>Balancing and Interpreting Chemical Equations</i>	200
10-3	The menu of reaction available within the first module in the program <i>Balancing and Interpreting Chemical Equations</i>	201
10-4	The computer screen at three different stages of a video clip	202
10-5	The computer screen at three different stages of an animated simulation	203
10-6	The computer screen illustrating the equation writing component of Module 1	204
10-7	The computer screen menu bar within the third module	205
10-8	The development of General Assertion 1	228
10-9	The development of General Assertion 2	229
10-10	The development of General Assertion 3	230
10-11	The development of General Assertion 4	231
10-12	The development of General Assertion 5	232
10-13	The development of General Assertion 6	233
10-14	The development of General Assertion 7	234



10-15	The development of General Assertion 8	235
10-16	The development of General Assertion 9	236
10-17	The development of General Assertion 10	237
10-18	The development of General Assertion 11	238
10-19	The development of General Assertion 12	239
10-20	The development of General Assertion 13	240
10-21	The development of Conclusion 1	242
10-22	The development of Conclusion 2	243
10-23	The development of Conclusion 3	244
10-24	The development of Conclusion 4	245
10-25	The development of Conclusion 5	246

## LIST OF TABLES

Number		Page
3-1	Schedule	36
4-1	Students' success in balancing chemical equations in Question 3 of pre and posttests	65
4-2	Comparison of representations of $3\text{Br}_2$ on the pre and posttests	68
4-3	Comparison of representations of $2\text{AlBr}_3$ on the pre and posttests	70
4-4	Students' misconceptions: Balancing and interpreting chemical equations	74
6-1	Percentage of occasions that each level of representation was accessed first, second or third in the learning sequence	105
6-2	The frequency with which various modules were accessed for each exercise attempted	110
6-3	The level of scaffolded worksheets selected by each dyad per exercise	111
6-4	The number of times (N) each module was accessed by each of the scaffolded dyads compared to the number prescribed by the scaffolded worksheet used in the exercise (P)	112
6-5	The total time in minutes devoted to the IMM software by dyads over the three sessions and the average times devoted by scaffolded and non-scaffolded dyads	123
7-1	Students' modes of collaboration	129
7-2	Instances of peer conflict	148
7-3	Conflict: divergence or convergence	149
7-4	The nature of the interactions between dyads	150

## CHAPTER 1

### INTRODUCTION

*The aim of science is to extend our experiences and reduce it to order.*

*Niels Bohr*

#### Introduction

Historically, many discussions have centered upon how the nature of science content affects its learning and teaching. This simple association is, however, inadequate to understand the complex relationships that exist between content, teaching and the process of learning (Carramaz, McCloskey & Green, 1981; Driver, 1980; Osborne & Wittrock, 1983). Fensham, Gunstone and White (1994) examined these relationships and suggested that the central issue should be the way in which we think about, and view, content and the processes of teaching and learning. This development led to a perceived need by these authors for a 'theory of content' that depicts the properties of science content and purposefully directs both learning and teaching practices.

The nature of scientific concepts can be exemplified by an examination of the domain of chemistry and its corresponding pedagogy. Concepts presented within this specialist domain are rarely directly experienced by students prior to formal instruction and, as such, students have not had meaningful common experiences of them to develop prior knowledge. This often results in an inability of students, who have not reached the 'formal' stage of development as defined by Piaget, to cope with these concepts during instruction (Herron, 1975).

Another characteristic of scientific concepts is their ability to be considered at three levels of representation. Within the domain of chemistry, these can be described as the macrophenomenon, sub-microscopic (or particulate) phenomenon and the symbolic levels. These levels of representation cause particular concerns for students who are required to

move from one level to another or to integrate multiple levels in order to understand and solve problems in Chemistry (Ben-Zvi, Eylon & Silberstein, 1987). In addition to these problems, the symbolic level of representation, which is an efficient means of communication, does assume that both the author and the reader are interpreting the symbolic language in the same manner. Not surprisingly, many students find chemistry a difficult subject to understand and learn (Finley, Stewart & Yarroch, 1982).

Chemistry is now listed as a prerequisite or preferred subject for most science or health-related tertiary courses at Western Australian universities. In addition, chemistry is considered by many students to be a subject of choice to provide a relevant, well-rounded education. As a result, chemistry must be made more accessible to students with a greater range of abilities. It is therefore important to understand these complex relationships and devise appropriate strategies and methodologies to assist students develop a better understanding of these difficult concepts.

The balanced chemical equation in the domain of chemistry reflects consistency with the law of conservation of matter, permits quantitative examinations of the relationships between reactants and products in an equation and is at the heart of chemistry. The ability to correctly balance chemical equations is a fundamental requirement of any chemistry curriculum. However, the process of balancing and interpreting chemical equations appears to cause many students much difficulty.

Research has focussed on the various techniques and associated reasoning required to effectively balance chemical equations (Herron, 1975; Karplus, 1977; Niaz & Lawson, 1985; Niaz & Robinson, 1992; Savoy, 1988). These techniques include the oxidation number method, the ion-electron method and the trial and error or inspection method.

According to Herron (1975), the oxidation number method requires students to use only concrete reasoning (as defined by Piaget) based upon the use of internalised algorithms. Herron also proposed that the ion-electron method requires formal or hypothetico-deductive reasoning (as defined by Piaget) because the student must use the

concept of oxidation, which derives meaning from a hypothetico-deductive system - atomic theory. The final method of trial and error was defined by Karplus, Lawson, Wollman, Appell, Bernoff, Howe, Rusch and Sullivan (1977), according to Niaz and Lawson (1985) to require formal reasoning because "...it requires a systematic approach to analysis and comparison of various combinations and possibilities" (p. 42). This position was further supported by Niaz and Lawson (1985) based upon their stance that the trial and error method was hypothetico-deductive in nature.

In addition to the level of reasoning required by such tasks, research has identified a range of factors that may affect the ability of some students to balance chemical equations. These include the logical structure of the task (Niaz & Lawson, 1985), the role of prior knowledge (Chandran, Treagust & Tobin, 1987), cognitive restructuring (Bodner & McNillen, 1986; Staver & Jacks, 1988), M demand (Pascual-Leone, 1970) and field dependancy (Witkin, Moore, Goodenough & Cox, 1977).

### **The Problem**

In view of these factors and the fact that the process of balancing chemical equations involves the consideration of an abstract, non-observable phenomenon with multi-level representation, it is not surprising that students have difficulty visualising the particulate level of matter and hence experience difficulty in balancing chemical equations with understanding.

These difficulties have significant implications for chemistry educators and classroom practice to ensure that the alternative frameworks, constructed by students for such abstract phenomenon are identified and appropriate intervention strategies implemented (Garnett, Garnett & Hackling, 1995).

The use of modern technologies and interactive multimedia has offered an alternative method of instruction that has exciting implications for the learning of

chemistry. This innovative technology permits the combination of non-linear linking of hypertext with the ability to manipulate various audio, video, graphical and textual media. As a result of these capabilities, interactive multimedia represents a unique opportunity as a tool to provide students in chemistry with accurate, concrete representations of the particulate nature of matter and with careful design and construction, the opportunity to reduce the cognitive demand and alternative frameworks generated by these tasks. However, there is a need for research to explore the most effective approaches to facilitating students' learning from these new multimedia resources.

### **Rationale and Significance**

School administrators and educators alike are coming under increasing pressure from students, parents and the community at large to incorporate new instructional technologies into the school curriculum. The costs associated with hardware, software, infrastructure and appropriate professional development can represent a significant investment. Schools have assumed that the new equipment, programs and practical outcomes are both cost and instructionally effective. The design and development of such interactive multimedia programs has a solid research base (Garnett, P.J., Garnett, P.J. & Hackling, M.W., 1995). However, the number of studies about students' interaction with interactive multimedia programs and their subsequent learning are indeed limited. Further, given the costs associated with the introduction and implementation of such learning technologies, class sizes experienced by teachers and the logistics imposed by these factors, would require students to work in small groups when using interactive multimedia software. Research findings are however scarce, regarding the manner in which students interact with each other whilst using IMM software and the subsequent impact of these interactions on the learning process.

Over the last five years a great deal of money and research has been focussed on the development of such innovative technologies and software for use in the classroom. One such application, developed by Garnett, Hackling and Oliver (1997a) was designed to

promote and enhance students' ability to balance chemical equations and understanding of the nature of chemical reactions at the particulate level.

This increased investment in development and use of learning technologies has focused attention on issues regarding the users' motivation to learn, information-seeking strategies, and learning.

These issues have a significant impact on the design of software and methodologies associated with instructional use of interactive multimedia technology including such features as audio, video and screen design, learner control and navigation, use of feedback, student activity and use of scaffolding. Interactive multimedia programs have the potential to make the learning process active, ensuring that users are interacting with, and not simply watching a screen. This notion of interactivity suggests that the learning process is, to some extent modified by the actions of the learner (Barker & Tucker, 1990; Slawson, 1993). Stemler (1997) considered that "interactive multimedia learning is a process, rather than a technology, that places new learning potential into the hands of the user" (p. 340). While such research has demonstrated the learning potential for interactive multimedia applications, Brooks (1993) has argued that, given the additional capabilities of these applications, the design of a growing number of these applications has not been well considered. Among the features of poorly designed interactive multimedia applications, Brooks (1993) lists the use of multiple fonts, irrelevant noises, insignificant frames and boxes, and confusing webs of possible instructional pathways and interactivity. Stemler (1997), in a review of relevant literature, considered that design features in multimedia applications such as screen design (colour, text, graphics and animation), learner control and navigation, use of feedback, and the use of video and audio elements affect the use and impact of the application in an instructional setting.

With the number of additional features of interactive multimedia applications that can be supplied by application designers, the potential exists for the learner to be exposed to an excessive amount of information and stimulus during use. Given the limited capacity of working memory (Biggs & Moore, 1993), it is plausible that the learner will only attend

to a fraction of the information presented. The problem facing educators is therefore to direct the learners' attention to the salient features of the multimedia application at relevant times, regardless of the amount or nature of information provided, thereby increasing the learner's focus and reducing the overloading of working memory. Nelson, Watson, Ching and Barrow (1996) reported that direct teacher scaffolding in a number of studies revealed significant contributions on student learning in younger children. The main difficulty presented by this form of direct scaffolding by teachers in the classroom setting is the number of children in the classroom, making such personal scaffolding to each student impossible.

The purpose of this study is to investigate the use of scaffolding, prepared in printed guides to enhance and direct student learning through an interactive multimedia software program designed to promote and develop skills of constructing and balancing chemical equations and the understanding of these equations. The results of this study will contribute to an understanding of: how scaffolding tools affect the way students interact with interactive multimedia programs; how scaffolding tools affect the way in which students interact and collaborate with each other whilst working on the interactive multimedia software; and, the effect of scaffolding on learning outcomes. Recommendations will be developed for improving the design of educational interactive multimedia applications and for pedagogies that will promote and enhance student learning.



## **Research Questions**

This study aims to address the following research questions:

1. How does scaffolding affect the way in which students interact with the IMM program?
2. How does scaffolding affect the way in which students interact and collaborate with each other whilst working on the IMM program?
3. Is there any evidence of enhanced understanding of the particulate nature of chemical reactions and success in writing and balancing chemical equations following use of this program with scaffolding?

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **Learning and Conceptual Change**

##### **Learning**

According to Biggs and Moore (1993), learning can be defined as “doing something differently as a result of experience and not because of physical growth, or other changes in the hard wiring” (p. 205). These authors suggested that we develop different forms of knowledge, which can be classified as tacit, intuitive, declarative, procedural and conditional. Existing knowledge allows us to construct meaning from our new experiences. This viewpoint reflects the classical work of constructivists, who believe that the learner constructs knowledge from interactions between prior knowledge and personal experience with natural phenomena (Carey, 1985; Carmichael, Driver, Holding, Phillips, Twigger & Watts, 1990).

Human learning encompasses a wide variety of mechanisms. At the most basic level, humans may learn by simple conditioning or its proposed variations as described by behaviourists (Bower, 1981). Such models do not adequately describe cognition because they fail to account for higher order thinking and cognitive skills. In contrast to behaviourist explanations, cognitive theory emphasises strategies and patterns of information processing (Ausubel, 1963; Neisser, 1967; Novak, 1977). A fundamental model of information processing that is the result of such cognitive-constructivism will now be discussed as a means of accounting for such higher order skills.

### Information-Processing Model of Cognition

The information-processing model of cognition defines three stages in the process of learning; each located in a separate, distinct memory system. These memory systems are linked by a central plan, which aids in the determination of what we attend to and how we attend to it by using prior knowledge and experience. The relationships between these stages have been portrayed by Biggs and Moore (1993, p. 207) and are shown in Figure 2-1.

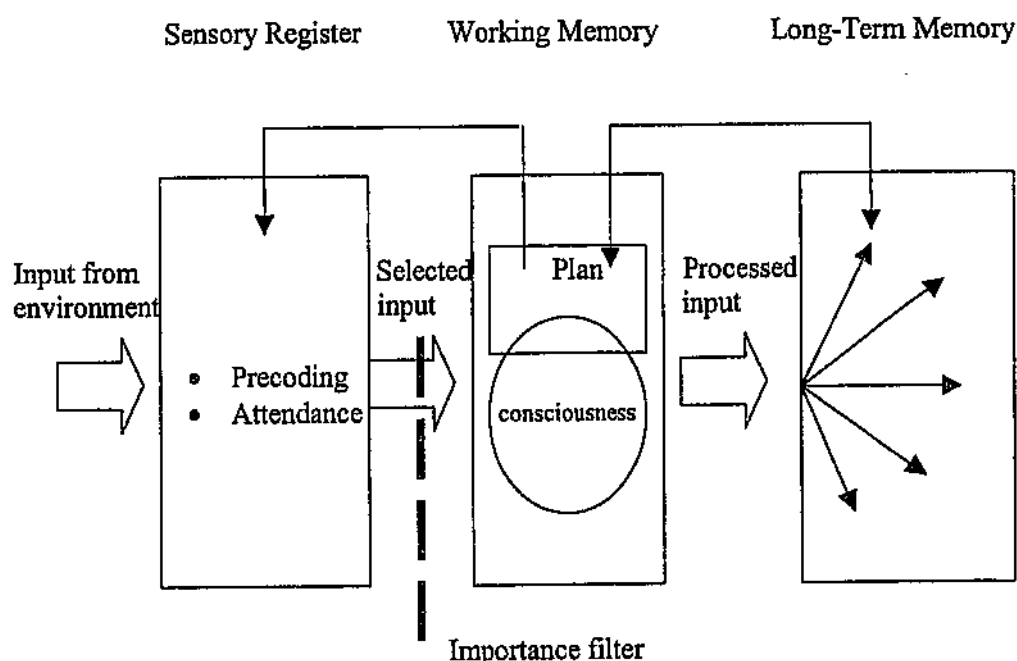


Figure 2-1 The three memory systems involved in processing sensory input, and their interconnections. (Biggs & Moore, 1993, p. 207)

The sensory register is that part of the memory system that receives information from our senses about the environment. Due to the fact that only certain, selected information is to be attended to and subsequently processed, all sensory information is pre-coded. Accordingly, all sensory information is retained for a period of up to one second, pending further processing (Atkinson & Shiffrin, 1968).

As a result of such precoding, where sensory inputs are prioritised, the information is passed through an importance filter, which determines which information will be processed further.

The selected, priority input from the sensory register then passes into the working memory, which has a limited capacity. It is here that information is processed using information and strategies retrieved from long-term memory. Such processing can include coding and rehearsal of information, which leads to the effective use of working memory and retention in long-term memory.

The limited capacity of the working memory is a key issue in the effective use of multimedia programs, due to the large amount of information that is presented to the learner and its potential to overload attention. It is for this reason that the appropriate scaffolding of students' observations is predicted to help students attend to relevant details at the appropriate time.

Information that has been processed in the working memory is then transferred and stored in long-term memory. There are three main theories associated with long-term memory, namely trace decay, associative interference and structuring.

Trace decay describes how information is stored as a trace that can fade at differential rates over time. This suggests that although fading of memories does occur, the degree or rate of fading may be dependent upon the quantity and quality of constructs developed within long-term memory. Associative interference suggests that the effectiveness of current learning depends upon the degree of similarity and interference with prior constructs. Finally, the theory of structuring suggests that the main factor in determining what we remember is our prior knowledge. Thus, as we learn, new information is coded after active interaction with existing, related constructs.

### **A Holistic Approach to Memory**

Integrating information into long-term memory is an active process, requiring the interaction of the three stages of memory, which is governed by a central plan. This central plan determines what we attend to and thus can be influenced by the physical properties of the stimulus, a pre-determined mental set or as the result of a physiological or internal state (Biggs & Moore, 1993).

Once information has been attended to, precoded and transferred to working memory, it is processed. The process as proposed by the structural theory of memory involves construction, which is the abstraction of information prior to storage in long-term memory (Disibio, 1982). Thus, learning is considered by the proponents of the structural theory (Neisser, 1967) to involve the dismembering of information and the subsequent coding into its constituent dimensions.

These dimensions (Figure 2-2), which include enactive, sensory, affective, temporal, spatial, semantic and logical memory (Neisser, 1967) are considered to exist on different levels of abstraction and are dependent upon the information being processed and the quantity and quality of prior knowledge constructs in long-term memory. Tulving (1985) simplified these seven dimensions into three basic kinds of memory, defined as procedural, episodic and semantic memory.

Such construction or dismembering was described by Osborne and Wittrock (1983) to be dependent upon real world experiences and occurred in such a way that it was consistent with prior constructs. The process of memory retrieval is considered to involve reconstruction or remembering, which involves the analysis and synthesis of information from constituent dimensions. This is shown diagrammatically in Figure 2-2.

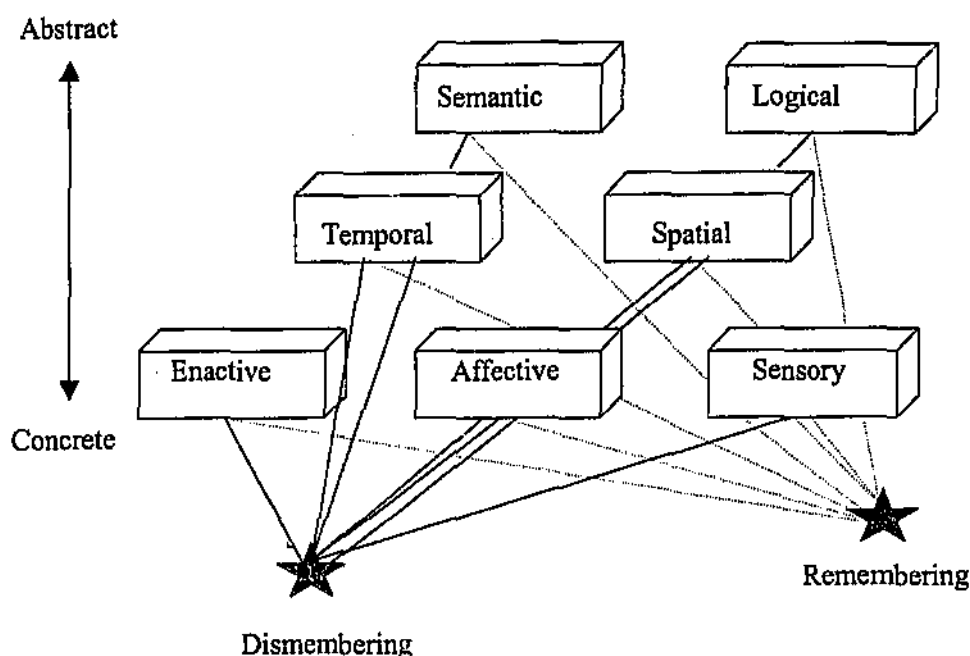


Figure 2-2 How learning is dismembered and remembered (Biggs & Moore, 1993, p. 221).

Another theory of memory by Ericsson and Kintsch (1995) proposed that any general description should include another mechanism omitted by traditional models of human memory. This mechanism is based upon the skilled use of storage in long-term memory that the authors termed long-term working memory and is in addition to the temporary storage of information referred to as short-term working memory. In their proposal, Ericsson and Kintsch (1995) described information in the long-term working memory as stored in a stable form, but in which accessibility is maintained only by the means of retrieval cues in the short-term working memory. Thus, the differentiation between long-term working memory and short-term working memory is based upon the durability of storage of information and the need for sufficient retrieval cues in attention for accessing long-term memory. Indeed, the distinction between short-term memory and long-term memory (Atkinson & Shiffrin 1968; Waugh & Norman, 1965) has remained a distinguishing feature of all major models of information processing (Cowan, 1988; Estes, 1988).

## **Memory Structures and Elements**

The work of information processing theorists supports the viewpoint that learning, memory and performance may be best understood by examining the three element paradigm: Instruction → Memory Structure → Learning Outcome. This is described by Gagne and White (1978), as a means of taking into account the processing of instruction, which necessarily involves the acquisition of particular kinds of memory structures. These structures are described by Gagne and White (1978) as the antecedents that enable the human learner to display retention and transfer in terms of new performances. Memory structures are defined, for the purpose of this discussion as the contents of long-term memory that result from learning and their organisation.

Two learning outcomes that are viewed as distinguishable classes of human performance (Gagne, 1972; Olson & Bruner, 1974) and are different objectives in many forms of schooling (Gagne & Briggs, 1974), include knowledge stating and rule application. Knowledge stating is defined by Gagne and White (1978) as the assertion of sentences in a form that preserves the propositional meaning of sentence inputs, including those of organised prose. These authors described rule application in terms of the application of intellectual skills in problem solving tasks.

Four basic kinds of organised memory structure have been proposed by researchers. These include networks of propositions, intellectual skills, images and episodes. From the work of theorists like Rohwer (1973) and Paivio (1971), we can deduce that for any one particular learning outcome, one memory structure may be of primary importance even though another may be mediating its recall and application.

The knowledge stating learning outcome is presumed by modern learning theory to be mediated by propositions or propositional networks (Bower, 1975), whereas the memory structures that enable the learning outcome of rule application are collectively referred to as intellectual skills (Gagne, 1972).

The memory structures of images may be visual, auditory, haptic or any combination, and are usually associated with concrete things or events. Episodic memory structures store information about temporally dated events and also temporal-spatial relations among such events (Tulving, 1972). Episodes represent events directly experienced by the learner and stored in such a way for easy recall. An important property of this memory structure, as described by Tulving (1972), is its 'autobiographical nature'.

The relationship between and within these memory structures is critical to the organisational structure or schemata proposed to occur within the long-term memory and is depicted in Figure 2-3. Thus, such memory structures represent a complicated and interlinked schemata in which information is coded and stored.



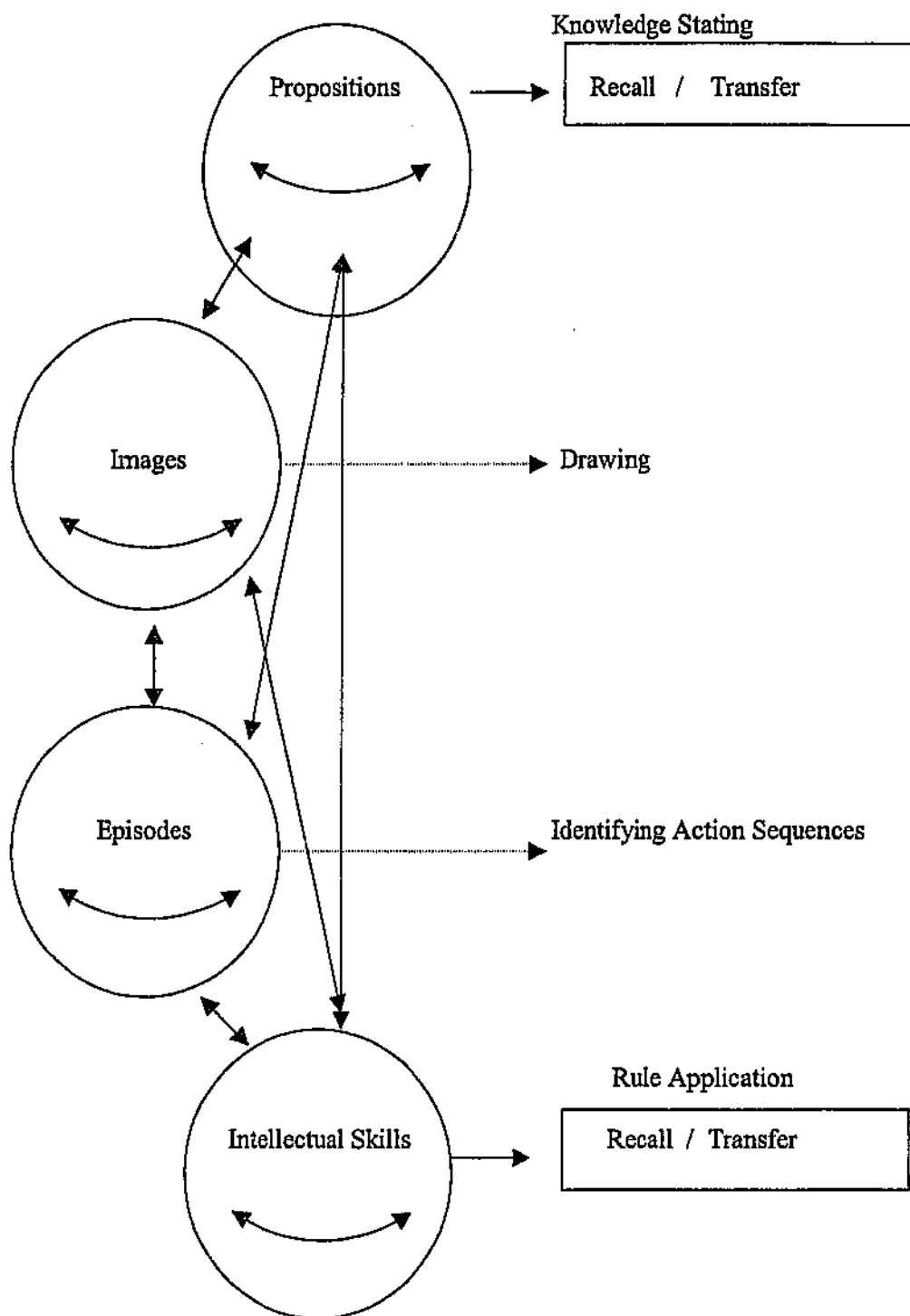


Figure 2-3 Diagram illustrating the interrelationships of memory structures and performance outcomes (Gagne & White, 1978, p. 195)

## **Constructivism**

### **The Role of Prior Knowledge**

The essential role and importance of a learner's prior knowledge has pervaded discussions thus far. Much research has been focussed on children's prior knowledge in domain specific studies. Such research, reports three major findings:

- children have firmly established views about events and phenomena prior to instruction;
- viewpoints held by many older children, which differ from the scientists' viewpoint, persist after instruction; and,
- children's viewpoints, if altered as a result of instruction, often alter in ways that were not intended (Osborne & Wittrock, 1983).

These conceptions or understandings that differ from scientists' explanations, which are also termed alternative conceptions or frameworks have been developed as a result of their perceptions, experiences and observations of the physical world. The commonness and persistence of these alternative frameworks have important implications for the way teaching and learning should be organised, the variety of instructional strategies used and the various considerations associated with each strategy.

The importance of prior knowledge has been acknowledged by proponents of constructivism and particularly by the Generative Learning Model (Osborne & Wittrock, 1983). This model is consistent with cognitive approaches to learning (Wittrock & Lumsdaine, 1977), information-processing models and research on the brain (Wittrock, 1980).

The basic premise of this model in the construction of meaning from sensory information, is that links are generated between new experiences and perceived relevant constructs that already exist in long-term memory. These tentative constructed meanings are then evaluated in terms of their consistency with prior constructs in long-term memory.

Such evaluation of tentative constructions may result in the rejection of the construct or may lead to the restructuring of the constructs in long-term memory.

Hewson (1981) proposed that only those constructions of meaning, including the associated restructuring of existing ideas, which appear plausible, are incorporated into long-term memory. Hewson (1981) also suggested that the number and quality of generated links in the initial construction and the way in which such constructions are evaluated are important in the way that new knowledge is stored in long-term memory, how well it is retained, and how useful it will be.

### **Language and Social Factors**

Two domains that have surfaced in the development of constructivism in explaining the process of learning science include personal and social construction. The personal constructivist movement supports the view that learning occurs as the result of interactions between the learner and their experiences. The tradition of social construction suggests that such knowledge-construction results from the learner being encultured into scientific discourses (Edwards & Mercer, 1987; Lemke, 1990). This social constructivist perspective emphasises that "knowledge and understandings are constructed when individuals engage socially in talk and activity about shared problems or tasks" (Driver, Asoko, Leach, Mortimer & Scott, 1994, p. 7).

Such enculturing occurs through the social institutions of science. Such a view does not imply that knowledge emerges from the scientific community purely through social processes. Harre (1986) proposed that scientific knowledge is constrained by how the world is and that scientific progress has an empirical basis, even though it is socially constructed and validated. This view of construction encompasses both personal and social constructivist ideologies.

The range of knowledge schemes that learners possess prior to instruction, are the result of prior experiences that have been shaped by socialisation into a 'commonsense view'. These commonsense views are able to adequately describe and explain everyday

experiences. These views are not solely personal in nature, but are representative of a culture and shared language. Driver et al. (1994) suggest that “children’s ontological frameworks evolve with experience and language use within a culture” (p. 8).

Such ‘commonsense’ explanations differ markedly from that presented by the scientific community. Such a division is described by Solomon (1993) to encompass “two worlds of knowledge” (p. 92). These two worlds of knowledge were described by Driver et al. (1994) to result in epistemological and ontological differences. This implies that learning will be hampered if such ‘commonsense’ views are dramatically different from those held by the scientific community.

### **The Cognitive Apprenticeship Model of Instruction**

The social constructivist movement, which is at the centre of a continuum of differing constructivist perspectives advocates that the foundation for learning is based upon the interactions between the student, instructor and the situated environment (Moshman, 1982). Popular social constructivist approaches to learning include cooperative learning (Brown & Palinscar, 1989), reciprocal teaching (Brown & Palinscar, 1989), scaffolded instruction (Beed, Hawkins & Roller, 1991) and the cognitive apprenticeship model (Collins, Brown & Newman, 1991)

Brown and Palinscar (1989) state that “cognitive apprenticeship methods try to enculture students into authentic practices through activity and social interaction in a way similar to that evident – and evidently successful – in craft apprenticeship” (P. 37). These authors also claim that the model supports learning in a domain by enabling students to acquire, develop and use cognitive skills in an authentic activity where the activity is central to the learning. This implies that the skills acquired are more than the physical skills usually associated with craft apprenticeships.

Collins et al. (1991) identified two major differences between traditional apprenticeship and cognitive apprenticeship. First, the tasks given to apprentice workers are a result of demands in the workplace, compared to schools, in which tasks given to students arise from pedagogical concerns. Second, the apprentice worker is required to demonstrate skills in situated contexts compared to students in schools, who are expected to decontextualise their knowledge and skills, so that they can be applied to a variety of situations and contexts. This suggests that learning in schools needs to be diverse so that students have the opportunity to apply their skills in a variety of contexts. In order to achieve this outcome, the application of such knowledge and skills in a variety of different settings needs to be reinforced and encouraged by the teacher whenever possible.

Collins et al. (1991, p. 457) contend that applying the apprenticeship model to cognition has two main benefits for learning. First, the method is primarily directed at teaching the processes that experts use to handle complex tasks and so consequently “conceptual and factual knowledge are exemplified and situated in the context of their use”. Second, the focus of this model is on the learning of cognitive and metacognitive skills and processes, which have not been emphasized in other methods.

Researchers have utilised the cognitive apprenticeship model to develop different teaching strategies, which has resulted in slight variations in the definitions of the various components. Collins et al. (1991) identified six teaching methods that characterise and define the instructional model. These components include:

- *Modelling*: A phase in which an expert carries out a task so that a student can observe and build a conceptual model of the processes that are required to accomplish the task.
- *Coaching*: Students are monitored during task completion by the expert, who provides feedback and then offers new tasks, which are aimed at raising student performance closer to that of the expert.

- *Scaffolding*: The expert assists the student to complete required tasks that have not yet been mastered by the student. This phase is coupled with fading; the gradual removal of the expert's support as students learn to do more of the task on their own.
- *Articulation*: This refers to a variety of methods utilised to encourage students to explain and think about what they are doing and as such consolidate their learning.
- *Reflection*: This phase is described by Collins et al. (1991) to "enable students to compare their problem solving processes with those of an expert, another student, and ultimately, an internal model of expertise". (p. 482)
- *Exploration*: This is the final phase in the cognitive apprenticeship model and involves encouraging students into a mode of problem solving on their own (Collins et al., 1991). This phase involves the fading of all support and problem setting so that students are given the opportunity to learn how to frame their own questions and problems.

Much research has been conducted on various aspects of the cognitive apprenticeship instructional model. Many of these studies (Ertmer & Cennamo, 1995; Garnett, 2000; Javela, 1996; Palinscar & Brown, 1984; Roth & Bowen, 1995; Scardamalia & Bereiter, 1985, Schoenfield, 1985) involved providing learners with a variety of strategies to lead them from novice to expert understandings and processes. These studies documented various aspects of the cognitive apprenticeship model and reported improved student achievement.

### **Scaffolded Instruction and Interactive Multimedia**

Scaffolded instruction is defined as a joint interaction in which the student and the teacher share the responsibility for the learning (Vygotsky, 1978; Wood, Bruner & Ross, 1976). Although Beed et al. (1991) described various types of scaffolding, the common essential features include the notion that the interaction occurs in a collaborative and supportive context; operates in the child's zone of proximal development; and that there is a gradual withdrawal of support from the teacher. The model of contingent scaffolded instruction as described by Wood, Wood and Middleton (1978) also includes a pattern of responses for the withdrawal of such support.

Such scaffolding in traditional formal instruction involves the teacher evaluating the subject and the likely areas of difficulty and then designing and implementing strategies to assist students during the course of learning. This type of planned scaffolding is not applicable for interactive multimedia applications, because the teacher has no control over the direction or path taken by the student or the organisation of the information in the multimedia program. The problem for this type of instruction remains in developing techniques to focus the student's attention on the salient content, regardless of the amount or nature of information being displayed.

Such teacher scaffolding into computer-based instruction has been cited as an effective supplement; however, most of this research has focussed on learning by young children (Clements & Gulla, 1984; Fay & Mayer, 1987). The general conclusion, as reported by Nelson, Watson, Ching and Barrow (1996) from these studies (Clements & Gulla, 1984; Fayer & Mayer, 1987) was that teacher scaffolding was an effective instructional supplement which when added to age-appropriate computer-based instruction significantly contributed to learning gains.

## Learning with Interactive Multimedia

Research has indicated that the capabilities of multimedia environments to store, interconnect and provide access to information results in significant enhancement to learning (Bosco, 1986; Fletcher, 1989). Such enhancement has been related to the increased interaction, flexibility that is afforded by the multimedia medium, motivational factors and the availability of immediate personal feedback compared to traditional modes of instruction. However, Bagui (1998) argues that the success of multimedia platforms in such instruction is related to the "... parallels between multimedia and the "natural" way people learn, as explained by the information processing theory" (p. 4).

Bagui (1998) stated that the success of multimedia can be attributed to the dual coding aspect of the information processing theory. According to this dual coding theory, Bagui (1998) considered that all sensory information is received in a variety of codes, which include text, audio, visual and imagery. In this paper, Bagui (1998) described the various advantages and issues surrounding the processing of information using these codes, which have been summarized below:

- *Text*: as a means of gaining information it has the advantages of being able to be processed at the learners' own rate; it is rehearsable; it is easy to store and can be preserved for long periods of time; it is efficiently stored and processed in a computer; and has the potential for providing some unique emphasis techniques, such as character size, colour, font, italics and underlining.
- *Audio*: as a means of gaining information it has the capability of being more easily comprehended, in particular by children and poor readers; it can be considered to be a more realistic and natural mode than displayed text as a means of presenting information; it does not distract visual attention from stimuli such as diagrams and therefore can be more engaging; it is a good means of conveying temporal information (Shih & Alessi, 1996). This researcher did indicate that poor speaking skills, such as poor diction, speaking too quickly,



can make it difficult for the listener to process and remember what was said, however, advances in digital technology could overcome such problems.

- *Visual*: visual illustrations help span linguistic barriers and overcome individual differences, isolate and identify important material, provide interaction with content, thus enhancing information acquisition and promoting learning. This code was described by Hodes (1992) as having the ability to make abstract concepts more concrete in nature.
- *Imagery*: imagery has been known to be effective for retaining verbal and non-verbal information. Bagui (1998) also reported that mental imagery, controlled by an individual, is considered a type of elaboration strategy, used by learners to increase the meaning of material by constructing internal associations among information in working memory and external associations between new information and existing knowledge. Edelstein (1981) reported that visuals, facilitated in information integration and subsequent high order learning of abstract concepts.

Bagui (1998) argued that the nature of multimedia permits the receipt of multiple codes as individuals are exposed to information through text, audio, visual and imagery, which facilitates the learning process. This was supported by Najjar (1996) in which he stated that learning is enhanced in the multimedia environment by the dual coding of information. According to the dual coding theory (Clark & Paivio, 1991; Paivio, 1971; Paivio, 1986), information is processed through one of two channels. These channels, which are generally independent, process either verbal information (text and audio) or non-verbal information (visuals and imagery). Bagui (1998) argues that learning is better when information is referentially processed through two channels compared to only one, and that such dual processing produces an additive effect because the learner creates more cognitive paths that can be used to retrieve information at a later date (Ellis, Whitehill & Irick, 1996; Levie & Lentz, 1982; Mayer & Anderson, 1991; Shih & Alessi, 1996).

Ericsson and Kintsch (1995) suggested that if students are required to follow instructions or engage in problem-solving that exceeds working-memory capacity, then their ability to understand, learn and solve problems may be hampered. Bagui (1998) stated that dual coding may permit schema construction, in which multiple elements of information are treated as a single element, which is categorised according to the manner in which it is to be used. Such schema construction would therefore be less taxing on the working memory, facilitating understanding. In addition, such dual processing permits the formation of additional cognitive paths that can be followed to retrieve the information (Mayer & Anderson, 1991; Paivio, 1967; Paivio & Csapo, 1973).

This view of interactive multimedia and its relationship to the information-processing model as argued by Bagui (1998) relates the information presented by such multimedia technologies to 'chunking' for the process of memory retention. In addition, such dual coding is also beneficial due to the varying sensory inputs required or preferred by different, individual learning styles. However, such sensory information is only useful for the purpose of learning, if the learner attends to the code. This was demonstrated by Brooks (1993) in which he stated that the additional capabilities of authoring and multimedia applications had resulted in many design flaws in instructional media that created additional 'noise' that distracted the learner's attention from the desired sensory information.

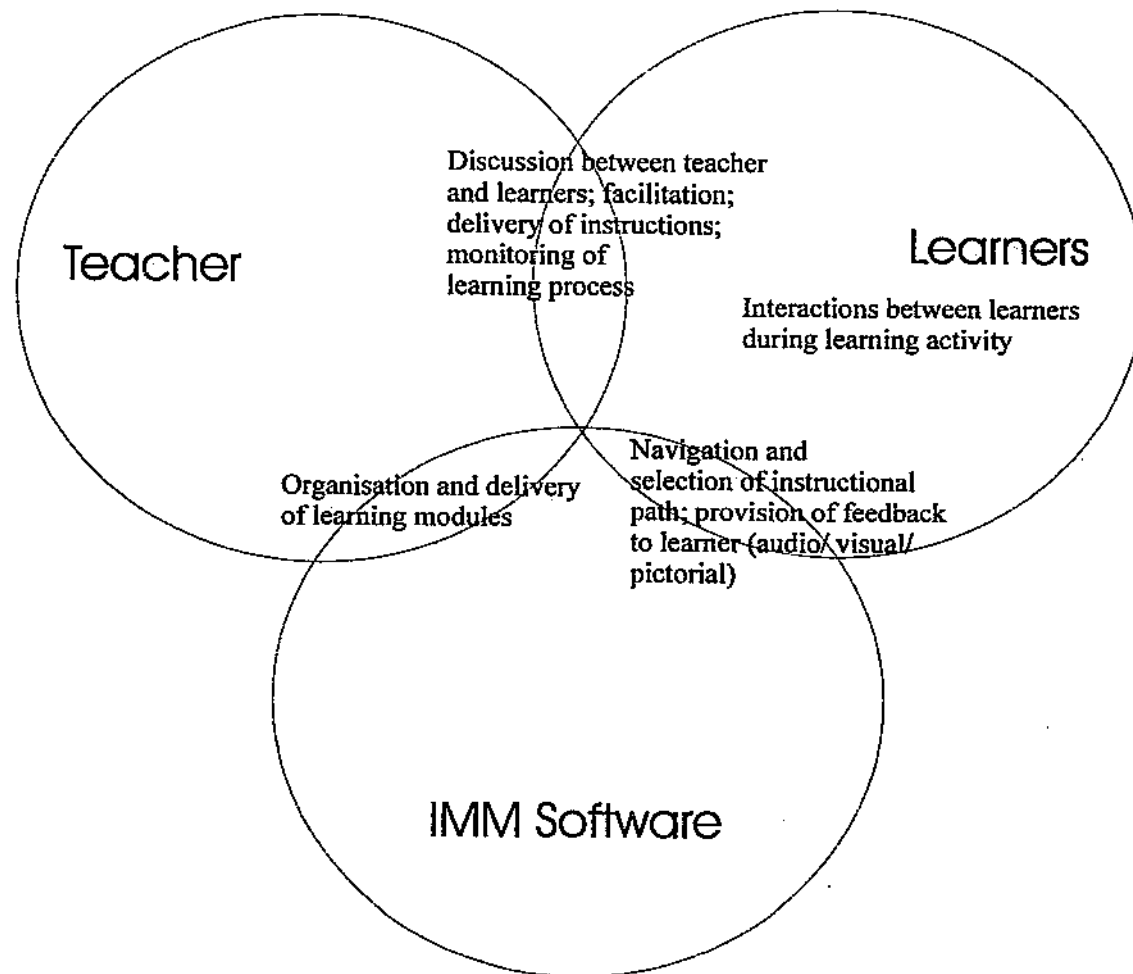
Several authors (Bucat, Tasker, Sleet & Chia, 1994; Garnett et al., 1995) have suggested that interactive multimedia could be used to improve students' visual imagery of chemical change and hence their understanding of the process of balancing chemical reactions and the particulate nature of matter. Garnett et al. (1995) proposed that the use of narrated video clips to enhance macroscopic visualisation and animated graphics to assist sub-microscopic visualisation, will provide learners with an appropriate mental model for constructing and balancing symbolic chemical equations (Garnett, Hackling & Hameed, 1993).

Much of this research has not closely examined the nature of the interactions that occur whilst students are watching or using the program. Jones and Berger (1995) analysed students' use, in particular, their use of media components of a computer-based instructional program entitled *Seeing Through Chemistry* through the use of students' log files. This study indicated that as many as 25% of students chose not to view any of the media segments. This statistic raises questions as to why students fail to access these components, or having accessed them, their reasons for exiting. These authors did explain however, that the analysis of such log files cannot reveal student intentions when using interactive multimedia programs.

Researchers of interactive multimedia need to take at least a three-pronged approach to research, examining both student learning (on quantifiable scales, and through interpretative research of individuals' experiences), effects on teachers and classrooms and the value of various media types for making unique contributions to the development of conceptual understanding. (p. 318).

In the IMM learning environment there are a number of interactions that occur between the teacher, learners and between them and the software. These interactions are summarized in Figure 2-4. While much research has focused on the interactions between learners and the IMM environment (Windschitl & Andre, 1998; Lee & Heller, 1997; Horiwitz & Feurzeig, 1994), little attention has been paid to the interactions that occur between the learners in this environment, whilst working collaboratively on IMM software.

Tao and Gunstone (1997) described peer collaboration as an activity "involving two (or more) students working together on a task that neither could do on their own prior to the collaborative engagement. These authors considered that the students started at



*Figure 2-4 The interactions that exist within an IMM learning environment*

roughly the same level of competence, and worked jointly on a task rather than individually on separate components as in cooperative learning" (p. 2). Damon and Phelps (1989) considered that peer collaboration provided a supportive environment that encouraged students to explore new ideas and then critically reflect on their existing conceptions. These authors stated that the engagement of peer collaboration was "rich in mutual discovery, reciprocal feedback, and frequent sharing of ideas" (p. 13).

Tao and Gunstone (1997) reported that Damon and Phelps (1989) defined two indices of describing the interactions that occur in peer learning: equality of engagement, which referred to the degree to which each learner was involved in the learning process; and the mutuality of engagement, which referred to the degree to which there was co-construction of knowledge between learners as opposed to individual knowledge construction. These authors considered the ideal learner interaction in a collaborative setting was high in both equality and mutuality. This idea was supported by Crook (1994) who also suggested that peer collaboration offered three cognitive benefits: articulation, conflict and co-construction.

Crook (1994) argued that in collaborative learning environments, learners make their ideas, explicit and public. In addition, they articulated their opinions, predictions and interpretations whilst working jointly on a task. He argued that such communication assisted both learners to gain a greater conceptual clarity. Tao and Gunstone (1997) considered conflicts to arise in collaborative settings when learners disagreed with the other's interpretations or approach to a task. This socio-cognitive conflict, produces a disequilibrium, which can only be resolved when students attempt to justify or defend their opinion after reflecting on their own conceptions. Finally, the co-construction of knowledge is based upon the Vygotskian perspective that learning occurs through the development of shared experiences and understandings in a social context. This viewpoint considers that understanding is constructed and shared between the learners prior to being internalized by each learner (Vygotsky, 1978).

Another factor reported to affect the degree of conceptual change afforded by IMM environments, is learner control. Stemler (1997) cites the work of Overbaugh (1994) and that of Schwier and Misanchuk (1993) who state that the term learner control has been defined and used in a number of ways in the literature, including content to learn, context within which to learn, method of presentation, provision of optional content, sequence in which to learn, amount of practice to undertake, the amount of time devoted to practice items, and the level of difficulty of the instruction. Miller (1990) contends that learners that have control over the learning process have increased satisfaction and that this makes the learners feel more responsible for their own learning. Hannafin (1984) states that the learner's existing knowledge, ability, use of structured guidance and the use of procedures for monitoring lessons all influence the effectiveness of learner controlled environments.

The degree of freedom permitted by user control designs remains a debated area in the literature. Laurillard (1987) argues that learners should be given more control of the content, access to content and interaction with the multimedia application, whereas Overbaugh (1994) believes that instructional components should be clearly identified and separated to facilitate the learners' selection and sequencing, perhaps through the use of menus. This was supported by the work of Schwier and Misanchuk (1993) who together with Stemler (1997) considered that learners could maintain control yet be directed by limiting the available choices on menus to learners.

In other research, Steinberg (1989) considered learner control to individualise the instructional process and make it more motivating. While this has been considered to be an advantage of interactive computer systems and the World Wide Web (WWW) as a learning environment, learners have often been found to lack the understanding and cognitive skills required to take full advantage of these learning environments (Heller, 1990; Trumball, Gay & Mazur, 1992). In addition, students often lack sufficient knowledge of the particular subject matter of an IMM software to select the most appropriate instructional paths through the software, in order to enhance and maximise learning opportunities.

These research studies suggest that if the nature of conceptual change in the IMM learning environment is to be understood, then the nature of the interactions between learners, and between learners and the IMM software need to be investigated.

There are currently few examples of educational research, which examine in-depth, the nature of students' interactions with interactive multimedia programs, and even fewer which seek to investigate how conceptual change occurs or the nature of interactions in these environments. Unless such interactions are given a priority in educational research, future technology will be developed without an understanding of the manner and processes of conceptual change in these environments. Such understanding is essential if informed decisions are to be made about the effective use of learning technologies and the design of intervention and scaffolding strategies that should be used to promote conceptual change

The methodology of this research project was informed by the following studies that examined conceptual change using programs that involved conceptually difficult material or higher order skills.

Kozma (1994) studied the alternative conceptions developed by students about chemical equilibrium as a result of using an interactive multimedia program called *Multimedia and Mental Models in Chemistry*. Kozma utilised an interpretative methodology, in which a 'think-aloud protocol' was used as students interacted with the software. The researcher then linked the various elements of conceptual change to specific instances in the interaction sequences.

Other studies including Roschelle (1991), Roth (1996) and Tao and Gunstone (1997) utilised verbal interactions between pairs or groups of students using the computer programs to reveal students' conceptions and understanding. Data collection in these studies included audio and video recordings of student interactions and the screen displays accessed. In addition, Roth played a participant role in his study, prompting students for their explanations of events and information on the display. Tao and Gunstone collected data by means of audio recordings of student interactions, pretest, posttest, school-based

assessment data, interviews and field notes of classroom observations. The data collection method employed, allowed for triangulation, which provided additional support for the various inferences about conceptual change made from primarily qualitative data.

Research to date has reported on the difficulties students experience in learning abstract chemistry concepts, and has described a variety of alternative conceptions held by them, both pre and post instruction. The unique capabilities of interactive multimedia to provide an accurate, concrete representation of abstract phenomenon that will promote understanding is an exciting development. Interpretative research is now needed to investigate the various interactions that take place during the use of interactive multimedia programs, the effect of scaffolding to direct student attention to particular information codes at appropriate sequences, the effect of this scaffolding on the way in which students interact with the multimedia software, and the effects of these factors on learning.



## CHAPTER 3

### METHODOLOGY

#### Design

The purpose of this study was to explore the effect of scaffolding on: students' interactions with an interactive multimedia (IMM) program; interaction between students in dyads whilst using the application; and on their ability to balance chemical equations and understand the nature of chemical reactions at the particulate level.

A mixed method design which incorporated multiple data sources, including pre and posttest data from six dyads, in addition to case studies of these pairs of students working on the program was used for this study.

Case studies are important in understanding and interpreting the education process (Linn & Erikson, 1986; Merriam, 1988). The collective case-study methodology was justified in this context in that the purpose of the research was to generate a detailed understanding of how scaffolding affects the way pairs of students interact with each other and with the IMM software. In addition, the purposeful sampling of a "typical-case" (Patton, 1990, p. 182) by selecting pairs of 'average' students from a high school science class should have increased the likelihood of generalisability, and hence external validity (Merriam, 1988), of results. However, the intention of the study was not to generate conclusions that can be widely generalised, but rather to construct a rich description of the interactions, so that the effects of scaffolding can be better understood.

The data collected within the study included audio recordings and researcher interview notes from pre and post interviews, video and audio recordings of students working on the program in pairs, computer screen capture of student interaction with the multimedia application and pre- and posttest results. The use of multiple data sources,

allowed for both *within methods* and *between methods* triangulation, which enhanced the reliability and validity of results (Campbell & Fiske, 1959) and contributed to the credibility of the research outcomes (Patton, 1990).

### **The Program**

The computer package *Balancing and Interpreting Chemical Equations* (Garnett et al. 1997a) consists of three discrete IMM modules (Molecular Equations, Ionic Equations and Interpreting Equations) that were designed to introduce students to chemical reactions and develop skills in constructing and balancing equations, and the understandings necessary for interpreting equations (Appendix 1).

The first module provided information and exercises relating to eight molecular chemical reactions. For each reaction, students were able to view and consider the reaction at three levels of representation, namely macroscopic, sub-microscopic or particulate and the symbolic level. Students were able to view a video demonstration showing the actual reaction as it occurred, view a simulation at the particulate level and/or write a balanced chemical equation.

The video segments in the IMM software package were short in duration, typically lasting about 20 seconds. They showed a close-up view of the reaction and were accompanied by a verbal description of reactants, products and the progress of the reaction. The animated simulations used dynamic computer generated graphics, which were of a similar duration to the video segments and were accompanied by an explanation of what each coloured particle represented and how they interacted with one another. Some highlighted particles were also labelled with their symbol to aid identification. The last level of representation provided students with the opportunity to balance equations, with both audio and visual feedback to inform them of their progress. Students were also provided with a practice set of 20 additional reactions to further develop their skills of writing balanced chemical equations.

The second module provided information and exercises relating to eight ionic chemical reactions. This module has a similar format to that of the first module and also permitted analysis at the three levels of representation.

The third module comprised seven parts in which students were challenged to develop their understanding of what chemical equations represented and to further enhance their skills in interpreting chemical equations.

In part 1 of the third module, students were required to interpret chemical equations by constructing molecular representations of the reactants and products for chemical equations based upon the coefficients in the equation. In part 3, students constructed molecular representations of the products formed in chemical reactions, from a given number of reactant molecules, which were simple multiples of the coefficients in the equations. In part 5, students constructed molecular representations of the products formed in chemical reactions, from a given number of reactant molecules present before a reaction.

In parts 2,4 and 6 students completed simple calculations that were designed to develop an understanding of the meaning of the coefficients in the chemical equations. In part 2, these interpretations were based upon the coefficients in the equation; part 4, upon multiples of the coefficients in the equation; and in part 6 students were required to calculate the number of particles present after a chemical reaction from the number of reacting molecules involved in a limiting reagent situation.

In part 7 students were required to write equations to represent reactions illustrated by 'before' and 'after' diagrams. The first four problems in this section involved simple multiples of the coefficients used in the equation, whereas examples 5 – 8 involved chemical reactions in which one reagent was a limiting reagent.

## **The Participants**

### **The Researcher**

The interpretation of qualitative data is subjective and requires the development of inferences and assertions from data. These interpretations are more likely to be valid if the researcher has the appropriate knowledge, experience and skills to undertake the task. The skills required by the researcher include: the ability to formulate relevant and precise questions that enable data to be elicited from the subject; to be adaptive and flexible in their approach as the research unfolds; excellent observation skills; and a lack of bias. Additionally, the researcher needs a rich understanding of chemistry and experience of teaching the subject.

As an experienced teacher of general science and chemistry at the secondary level, the Researcher has taught a range of introductory chemistry courses to students in Years 8 and 9, as well as teaching comprehensive chemistry courses to students in Years 10 to 12. The Researcher's various roles in secondary schools as Year 12 Chemistry Coordinator and Head of Chemistry, have provided additional experiences in the identification of alternative conceptions and the implementation of suitable instruction designed to change such conceptions. The Researcher's knowledge of this subject matter and extensive experience have provided an insight into the problems faced by students as they begin to learn the fundamentals and the language of chemistry, and how these problems may inhibit student progress and ultimate success.

### **Student Participants**

The participants in this study were 15 year old, Year 10 male students from a large, single sex independent boys' school in Perth, Western Australia. The participants were enrolled in one of six Year 10 chemistry classes taught at the school, one of which was taught by the Researcher. Twelve students were selected by purposeful sampling, based upon their ability to communicate, willingness to work in pairs cooperatively and their ability to achieve a 'B' or 'C' grade at the end of the year based upon previous results. These students were then arranged in pairs for the remainder of the study.

## **Pilot Study**

The IMM application, which was used in this study, *Balancing and Interpreting Chemical Equations* (Garnett et al., 1997a) was very new and had not been used previously with students at this school. For this reason, a class of Year 10 students, who were at a different stage of the curriculum compared to the remaining classes in that year group were used to assist in a pilot study.

These students were given an introduction to the IMM application by their teacher and then allowed to work through the program uninterrupted in pairs. The Researcher observed student progress through the application and took sufficient notes to enable the manner in which they used the program to be reconstructed and identify the difficulties that they experienced. At the conclusion of a series of three lessons using the program, two students were selected and interviewed about their use of the program for learning chemistry. These interview sessions were also used as an opportunity to pilot the interview and pre-test questions. Information from this pilot study was used as a basis for developing and refining the scaffolding materials, interview and test instruments that were used in the main study.

## **Procedure**

The procedure involved two phases of research: a pilot study and the research project. The pilot study, which has been previously described, provided information about how students utilised the IMM software package and the nature and quality of interactions they had with each other and with the IMM package. These interactions guided the development of a set of interview questions and a pencil and paper test directed to ascertain the degree with which students were able to balance chemical equations and understand the particulate nature of matter.

The research methodology was an interpretative, collective case study approach supplemented with data from pre and posttests. In this design, a total of 12 students were selected by purposeful sampling and arranged in pairs as previously described to utilise the IMM software *Balancing and Interpreting Chemical Equations* (Garnett et al., 1997a). Students were observed by the researcher whilst using the IMM software and various aspects of their interactions were recorded in greater detail using various media. Student interactions with the IMM software were recorded by both screen-capture software and videotape recordings. This videotaped data also served the purpose of recording student interactions within their dyad in addition to audio recordings made of their verbal interactions and exchanges.

Prior to interaction with the IMM software, the students in the study underwent a pencil and paper pre-test designed to elucidate their understanding of balancing chemical equations and the particulate nature of matter. The student dyads were then randomly assigned into two groups to either use the IMM software with scaffolding or use the software without scaffolding. Students worked with the IMM software on alternate days for a total of three sessions of 60 minutes maximum duration. These sessions were conducted after school and are illustrated in the schedule shown in Table 3-1.

Table 3-1:  
*Schedule.*

Day of the Week	IMM with Scaffolding	IMM without Scaffolding
Monday	Session 1	-
Tuesday	-	Session 1
Wednesday	Session 2	-
Thursday	-	Session 2
Monday	Session 3	-
Tuesday		Session 3

Following this schedule, the student dyads underwent a post interview and a pencil and paper posttest, to elucidate their understanding of balancing chemical equations and the particulate nature of matter. The methodology employed in this research is shown diagrammatically in Figure 3-1.

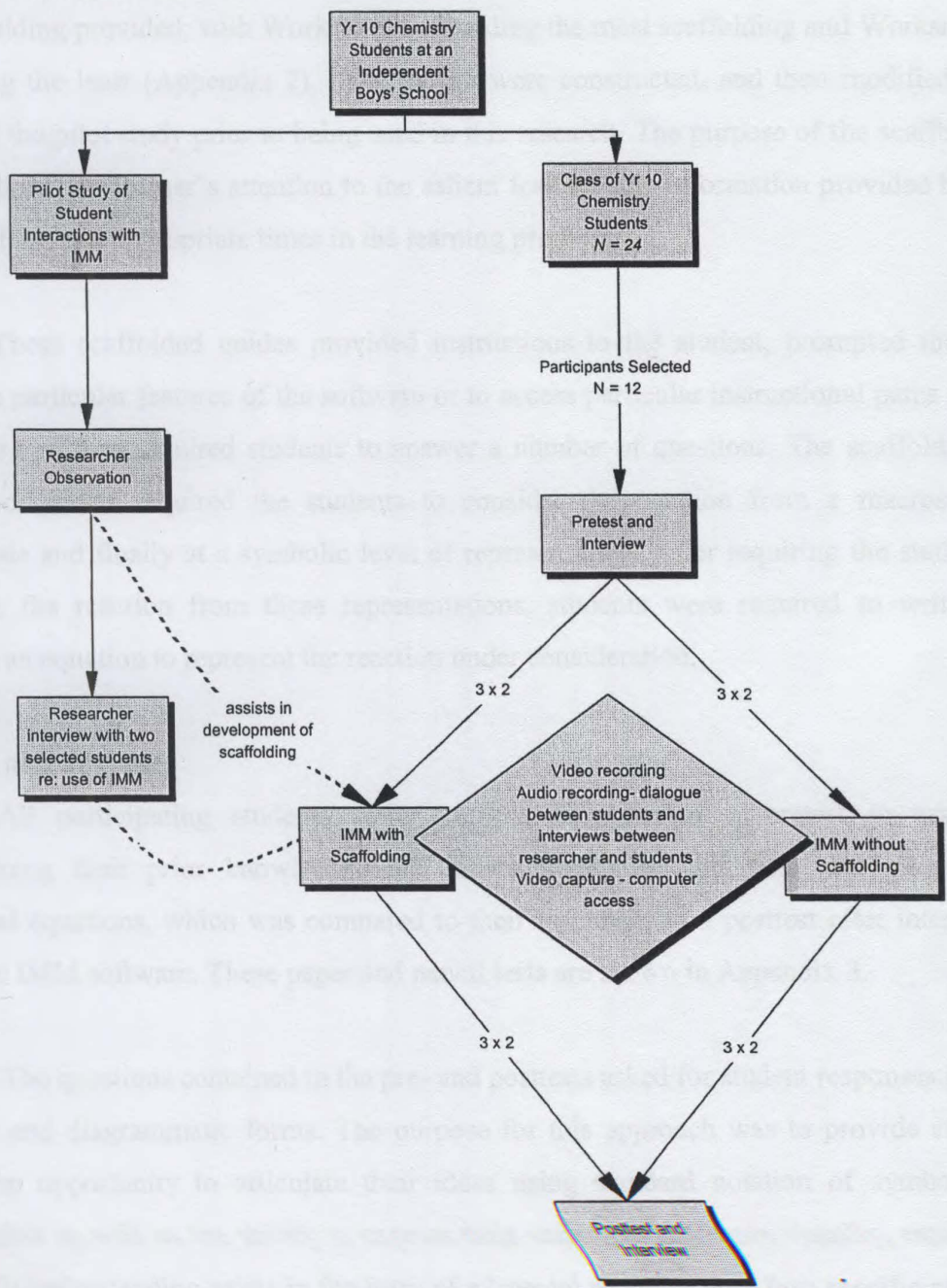


Figure 3-1 Methodology employed for research into the use of scaffolding to improve student learning with interactive multimedia programs in chemistry.

## **Instruments**

### **Scaffolded Guides**

The scaffolded guides were prepared as three worksheets that varied in the degree of scaffolding provided, with Worksheet 1 providing the most scaffolding and Worksheet 3 providing the least (Appendix 2). The guides were constructed, and then modified as a result of the pilot study prior to being used in this research. The purpose of the scaffolding was to direct the learner's attention to the salient features and information provided by the IMM software at appropriate times in the learning process.

These scaffolded guides provided instructions to the student, prompted them to examine particular features of the software or to access particular instructional paths of the software and then required students to answer a number of questions. The scaffolding in these worksheets required the students to consider the reaction from a macroscopic, particulate and finally at a symbolic level of representation. After requiring the student to examine the reaction from these representations, students were required to write and balance an equation to represent the reaction under consideration.

### **Pretest and Posttests**

All participating students were required to complete a pretest to assist in determining their prior knowledge and understandings in balancing and interpreting chemical equations, which was compared to their responses to a posttest after interaction with the IMM software. These paper and pencil tests are shown in Appendix 3.

The questions contained in the pre- and posttests asked for student responses in both written and diagrammatic forms. The purpose for this approach was to provide students with the opportunity to articulate their ideas using standard notation of symbols and formulas as well as the ability to express their understanding more visually, especially if such understanding exists in the form of a 'mental model' rather than specific propositions or schema.



The questions in the pretest and posttest were designed to reveal students' changed understandings of:

- chemical formulae and what they represent in terms of the number and types of atoms involved in the structure;
- the particulate nature of chemical substances;
- the particulate processes that are represented by balanced chemical equations; and
- limiting reagents

### **Interviews**

In order to further elucidate and assess students' understanding, all students were interviewed after completing both pre and posttests. The Researcher did not utilise a set schedule of interview questions in this process, but rather attempted, through questioning to elicit more detailed explanations of idiosyncratic responses from students to paper and pencil test questions.

### **Data Analysis**

A substantial amount of qualitative data was collected prior, during and after the intervention period. These qualitative data were supplemented with quantitative pre and posttest results in order to cross-reference and triangulate research findings about the selected group of students. The data from the pre and post interviews, and the written documentation, researcher's field notes, audio and video recordings of the dyads and their interactions collected during the intervention, and screen-capture recordings were used to generate a 'case history file'.

The data from pre and posttests were compared to establish changes in students' understanding of chemical formulae, the particulate nature of chemical substances, the particulate processes represented by balanced chemical equations and of limiting reagents. These conceptual changes were summarised for each student. Audio recordings from both

pre and posttest interviews were transcribed and salient aspects of dialogue noted for each student and attached to the relevant question on the pre or posttest. Finally, data collected during interaction with the IMM software included screen capture, researcher's field notes, audio and video recordings of the dyads were analysed. The screen capture data was logged for each dyad to determine the number of times different instructional paths were accessed. Video recordings of the dyads using the IMM software were analysed by viewing, to determine the amount of time each student in the dyad had user control. These data were also used to calculate the total instructional time that each dyad worked on the IMM software. Both audio and video recordings of student interactions whilst using the IMM software were analysed classified as interactions occurring between students working in isolation or together. The sum of the joint on-task interactions was calculated, presented as a percentage of the total interactions and arbitrarily assigned as being high, medium or low, with respect to joint on-task engagement (with over 80% considered high, 60-80% regarded as medium and less than 60% as low). The transcribed audio data, recorded whilst students used the IMM software, was analysed to make inferences regarding the equality and mutuality of engagement. These inferences were based on an interpretative assessment of the collaborative sequences, rather than specific calculations of occurrences of certain events or utterances.

These data were analysed to elucidate information and develop assertions about the main themes of the research, which included:

- Theme A: Students' understanding of balancing chemical equations
- Theme B: Students' understanding of the particulate nature of matter.
- Theme C: The manner in which students interact with the IMM software.
- Theme D: The manner in which students interact and collaborate whilst using interactive multimedia software.

The quantitative data obtained from the pre and posttests provided additional data on Themes A and B, which was used as a means of cross-referencing and triangulating the

qualitative data. The relationships between the research questions, multiple data sources and methods of analysis are summarised and illustrated in Figure 3-2.

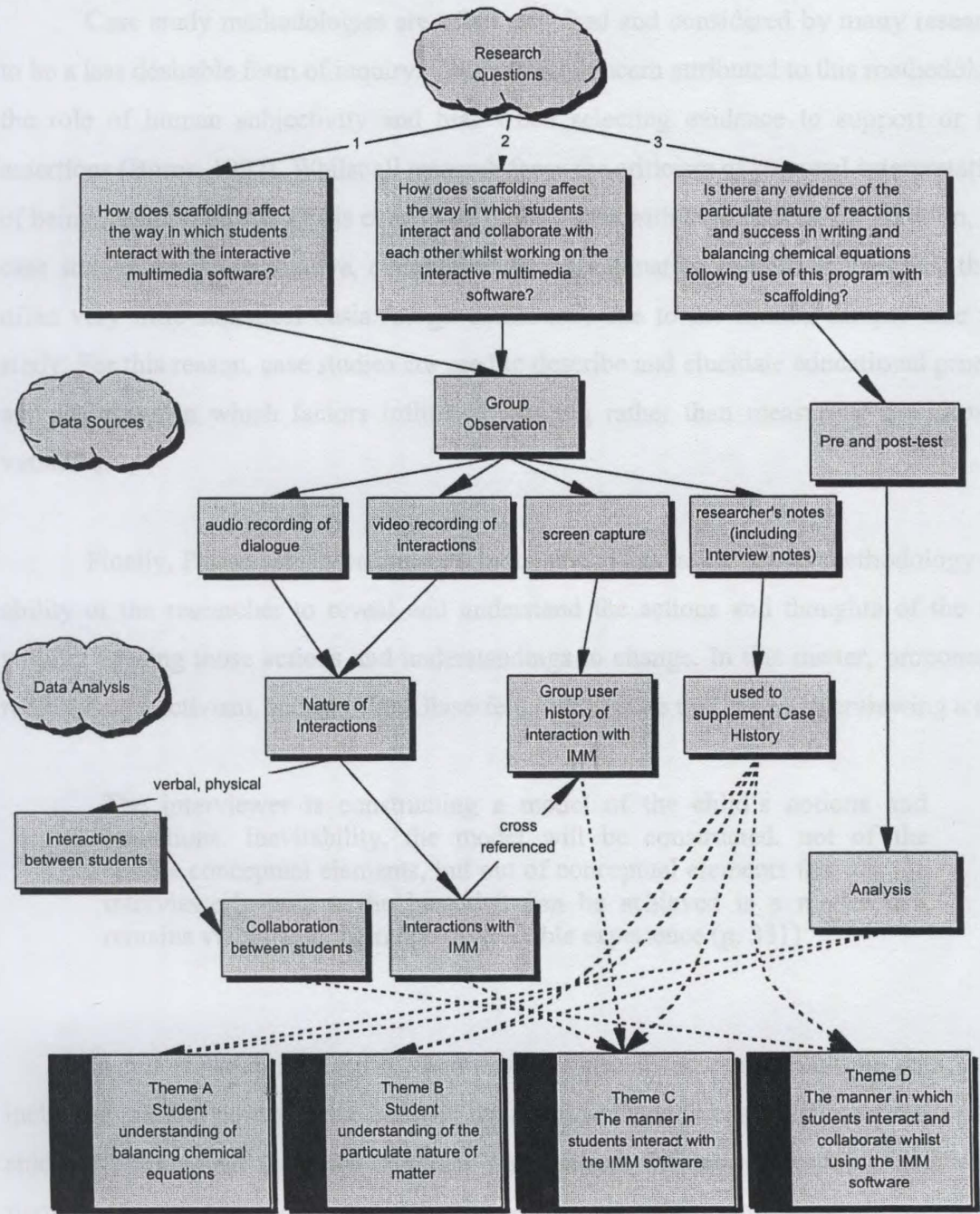


Figure 3-2 The relationship between the research questions, data sources and methods of analysis.

## **Limitations of the Research**

Case study methodologies are often criticised and considered by many researchers to be a less desirable form of inquiry. The greatest concern attributed to this methodology is the role of human subjectivity and bias when selecting evidence to support or refute assertions (Burns, 1997). Whilst all research faces the criticism of personal interpretation or of being impressionistic, this is even more problematic with case studies. In addition, while case studies can be qualitative, quantitative or a combination of both approaches, there is often very little statistical basis for generalisation, due to the limited sample size under study. For this reason, case studies are used to describe and elucidate educational processes and the ways in which factors influence learning rather than measuring the impact of variables.

Finally, Patton (1990) considers a more severe limitation of this methodology is the ability of the researcher to reveal and understand the actions and thoughts of the actors without causing those actions and understandings to change. In this matter, proponents of radical constructivism, such as Von Glaserfeld (1988) state that, when interviewing a child:

The interviewer is constructing a model of the child's notions and operations. Inevitably, the model will be constructed, not of the child's conceptual elements, but out of conceptual elements that are the interviewer's own ...the best that can be achieved is a model that remains viable with the range of available experience (p. 331)

In this research a mixed method design which incorporated multiple data sources, including pre and posttest data from six dyads, in addition to case studies of these pairs of students working on the IMM software was utilised. The use of multiple data sources, permitted a case history file to be developed for each student and dyad within the study, which enabled data to be confirmed and triangulated with other data sources. The development of the case history file provided an audit trail by which assertions can be traced back to data and provide an assurance of the credibility and trustworthiness of the findings. This triangulation, together with initial trials in the pilot study and the extensive

experience of the Researcher in teaching Chemistry also assured the reliability and validity of the instruments used in this study.

Additional limitations of this specific study were that the study only involved 15 year old, Year 10 male students from a large, single sex independent boys' school in Perth, Western Australia. Given the nature of this school, and the clientele that it attracts, many of these students come from home environments where education and high academic results are highly valued. Many of these students, due to the socioeconomic status of their parents had ready access to computers in the home and were computer literate. These specific features of the chosen sample produce additional limitations, which may reduce the applicability of the many of the findings to Year 10 students in general.

While the limitations of this method have been clearly defined and the ability to statistically generalise to a wider population significantly reduced, the interpretative case study employed, with its multiple data sources, did provide a rich descriptive holistic, yet detailed account of the six dyads in an IMM environment using the software application *Balancing and Interpreting Chemical Equations*. The conclusions that have been made, while applicable only to these students in the study, provide an insight into learners' conceptual changes and the interactions between learners working collaboratively and between learners and the IMM software, and how these understandings and interactions differ when the students are provided with suitable scaffolding. These issues have not been reported to a great extent thus far in research literature.

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **STUDENTS' UNDERSTANDING OF THE PARTICULATE NATURE OF MATTER**

##### **Introduction**

This Chapter presents and interprets data related to students' representations of atoms and the way in which they are arranged into molecules, and in particular students' understanding of chemical symbols, the meaning of subscripts, coefficients as used in balanced equations and the structure of molecules. The data were obtained by comparing student responses to Questions 1-5 on the pre- and posttests, which were triangulated with data drawn from videotapes and interviews. These data are discussed and then several assertions are made related to this theme.

The first two questions regarding the particulate nature of matter presented and asked for information in two formats, symbolic and pictorial. The responses from all subjects on pre- and posttests, in addition to corroborating evidence from interviews are summarised and discussed on the following pages.

##### **Knowledge of Symbols, Chemical Formulae and the Meaning of Coefficients**

Responses to Questions 1 and 2 on the pretest demonstrated that all students had a sound knowledge of the symbols involved (those of nitrogen, hydrogen, chlorine and carbon). This knowledge would be considered to be a revision of work studied in Year 9 Chemistry at this school.

Question 1	Explain what the following formulae represent. Your answer should include the number and types of atoms involved.
a)	$\text{NH}_3$
b)	$2 \text{HCl}$

*Figure 4-1 Question 1 from the pre and posttests*

In Question 1a, pretest results indicated that all students displayed an awareness and understanding of the meaning of the subscript 3 in the formula of ammonia, however, Students 1 and 3 considered the subscript in terms of moles ie. one mole of nitrogen and three moles of hydrogen atoms, whereas Students 2, 4, 5, 8 and 10 responded in terms of atoms ie. one atom of hydrogen and three atoms of nitrogen. Students 6, 7 and 9 were more ambiguous, by stating that it was either 1 x nitrogen and 3 x hydrogen or used the term particles.

The majority of students considered the formula of  $\text{NH}_3$  to represent an individual molecule, although only Students 6 and 9 stated that the nitrogen and hydrogen atoms were in fact bonded together (although Student 9 indicated that the bonded structure was termed an atom).

Student responses on the posttest were in general, more descriptive and a greater number of students considered that the atoms were forming a bonded structure, termed a molecule. Evidence for this statement comes from Students 2, 3, 4, 6, 8 and 10 who indicated an awareness that the nitrogen and hydrogen atoms were bonded together to form a substance. Only Student 3 considered the 3 x H to be an aggregate of three hydrogens together, yet correctly drew the structure of ammonia in the subsequent question showing the molecular nature of the substance.

When responding to Question 1b on the pretest, Students 1 and 5 considered the coefficient ( $2 \text{HCl}$ ) as meaning 2 x hydrogen and 2 x chlorine. They did not indicate any awareness that the one hydrogen and one chlorine atom were combined to form a molecule

or aggregate of particles. Instead they considered these atoms as independent units. Students 2, 3, 4, 6, 8 and 9 considered that the symbols represented two HCl molecules, each with one hydrogen and one chlorine atom (Students 6 and 8 specifically named the molecule as hydrochloric acid). Student 7 considered the symbols represented a structure consisting of two hydrogens and only one chlorine. This student only applied the meaning of the coefficient to the first chemical symbol. Finally, Student 10 considered that the symbol represented an aggregate of particles that consisted of two hydrogens and two chlorines all joined together. The interpretations of Students 7 and 10 were confirmed by interview.

- Interviewer:** Can you explain what the 2 in front of HCl means?
- Student 7:** Yeah ... it means that there is 2 hydrogen things ... atoms and only 1 chlorine atom.
- Interviewer:** Why is the number placed in front of the formula?
- Student 7:** Well ... you can place it there or after the hydrogen symbol ... can't you?
- Interviewer:** Can you think of an example that places the number after the symbol?
- Student 7:** No ... yeah I can. The one in the question ... ammonia. It has a three after the "H"
- Interviewer:** Could that be written another way?
- Student 7:** Yes N3H. It is just personal preference.
- Interviewer:** What do you call that?
- Student 7:** Ammonia (said with doubt)?
- Interviewer:** Good ... yes you are correct, however, what I meant was what do you call the ... structure?
- Student 7:** Umm ...not sure...I think it's just called a particle.

*Figure 4-2 Pretest interview A with Student 7*



<b>Interviewer:</b>	Before you move on to the next question, can you tell me why you put this answer [answer to question 1B]?
<b>Student 10:</b>	well ... $2\text{HCl}$ means two hydrogen and two chlorine atoms.
<b>Interviewer:</b>	How are they arranged?
<b>Student 10:</b>	What do you mean?
<b>Interviewer:</b>	How are those two hydrogens and two chlorines arranged .... organised?
<b>Student 10:</b>	Don't know ... I think that they are joined together?
<b>Interviewer:</b>	What do mean together?
<b>Student 10:</b>	...all joined together a hydrogen joined to the other hydrogen then to the chlorine atoms.
<b>Interviewer:</b>	...so does the symbol $2\text{HCl}$ have four atoms all joined together?
<b>Student 10:</b>	... yeah ... guess so.
<b>Interviewer:</b>	What do you call this structure or group or particles?
<b>Student 10:</b>	It's a molecule consisting of two hydrogens and two chlorines

*Figure 4-3 Pretest interview A with Student 10*

On the posttest, all students correctly interpreted the coefficient as meaning two molecules of  $\text{HCl}$ , except Students 5 and 7 who showed no change in their opinions from those expressed in the pretest. Student 10 still considered the two molecules to be attached or bonded together. No attempt was made to distinguish between intermolecular and intramolecular bonding, which otherwise would have indicated a well-developed understanding of particulate relationships. All students did show an improved understanding of the chemical terminology, such as the term molecule, compound and atom. These observations for Students 7 and 10 were confirmed by interview.

**Interviewer:** Can you explain what the 2 in front of HCl means?

**Student 7:** Yeah ... it means that there is hydrochloric acid molecules bonded together

**Interviewer:** Why is it called a molecule?

**Student 7:** don't know ... isn't that what you call atoms that are joined together?

**Interviewer:** Let's leave that for now. Why is the number placed in front of the formula?

**Student 7:** To show that there are two.

**Interviewer:** Can you represent 2 molecules of HCl by putting the number after the "H" or "Cl"?

**Student 7:** No ... that is not going to be hydrochloric acid but something else.

**Interviewer:** Why did you join them together?

**Student 7:** ... cause there are two of them together.

**Interviewer:** How do you know that they are together?

**Student 7:** Because there is a two in front of the formula.

**Interviewer:** So... what does the number 2 mean?

**Student 7:** It means that there are two HCl things together ... joined.

**Interviewer:** How could you write the formula for two HCl molecules that were not together?

**Student 7:** ... (unable to decipher – grunt)

**Interviewer:** Should I repeat the question?

**Student 7:** No ... maybe with a two in front but separate from the HCl? Is that correct?

**Interviewer:** Can you think how else this could be represented?

**Student 7:** No.

*Figure 4-4 Posttest interview A with Student 7*

**Interviewer:** Before you move on to the next question, can you tell me why you put this answer [answer to question 1B]?

**Student 10:** well ... 2HCl means two hydrogen and two chlorine atoms.

**Interviewer:** How are they arranged?

**Student 10:** What do you mean?

**Interviewer:** How are those two hydrogens and two chlorines arranged .... Organised?

**Student 10:** Don't know ... I think that they are joined together?

**Interviewer:** What do you mean together?

**Student 10:** ...all joined together a hydrogen joined to the other hydrogen then to the chlorine atoms.

**Interviewer:** ...so does the symbol 2HCl have four atoms all joined together?

**Student 10:** ... yeah ... guess so.

**Interviewer:** What do you call that structure?

**Student 10:** a molecule.

*Figure 4-5 Posttest interview A with Student 10*

- |            |                                                                                                          |
|------------|----------------------------------------------------------------------------------------------------------|
| Question 2 | Draw a diagram to represent the following substances at the particulate level. Label each atom involved. |
| a)         | $\text{NH}_3$                                                                                            |
| b)         | 2 HCl                                                                                                    |

Figure 4-6 Question 2 from the pre and posttests

For Question 2a on the pretest, all students were able to draw a representation of ammonia, which had the correct structural arrangement, with a couple of students attempting spatial representations. In Question 2b, Students 1, 2, 4, 6 and 8 were able to correctly interpret the  $2\text{HCl}$  to mean two distinct or separate molecules of HCl. Student 2 drew two distinct molecules of HCl, however he linked them with a dashed line, as opposed to the solid line that linked the hydrogen and chlorine atoms. The student was questioned about its significance in the following interview, which indicates not only an understanding of the representation of matter but also of the relationship of macroscopic properties to the particulate nature of matter.

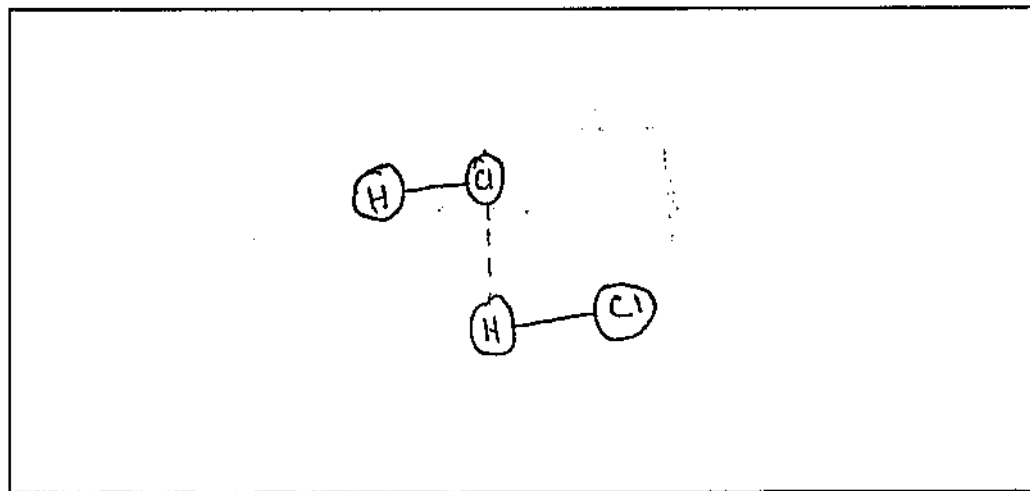


Figure 4-7 Work sample from Student 2 for Question 2

- Interviewer:** Why have you drawn a dashed line between this hydrogen and chlorine and solid lines here and here [pointing to the HCl molecules]?
- Student 2:** I have drawn two hydrochloric acid molecules. They each have a hydrogen atom and a chlorine atom that have been joined by covalent bonding. The dashed line is the force that holds the hydrochloric acid molecules together in the liquid state.
- Interviewer:** What do you mean by covalent bonding?
- Student 2:** It's when electrons are shared between atoms.
- Interviewer:** Why are they shared?
- Student 2:** To make each atom happy ... I mean stable. To have a complete octet of electrons.
- Interviewer:** OK ... very good. Why draw the dashed line?
- Student 2:** All molecules must be held together in a liquid state otherwise they would move away and then it would be a gas. The line is a force that holds them together.
- Interviewer:** How does this force form?
- Student 2:** Don't know.
- Interviewer:** Does it exist between all molecules?
- Student 2:** No .... Only between solid molecules and liquid molecules.

Figure 4-8 Pretest interview A with Student 2

Students 3 and 5 correctly interpreted the multiple meaning of the coefficient, but concluded that the aggregate of four particles represented were structured as one molecule. This was confirmed by interview with Student 5.

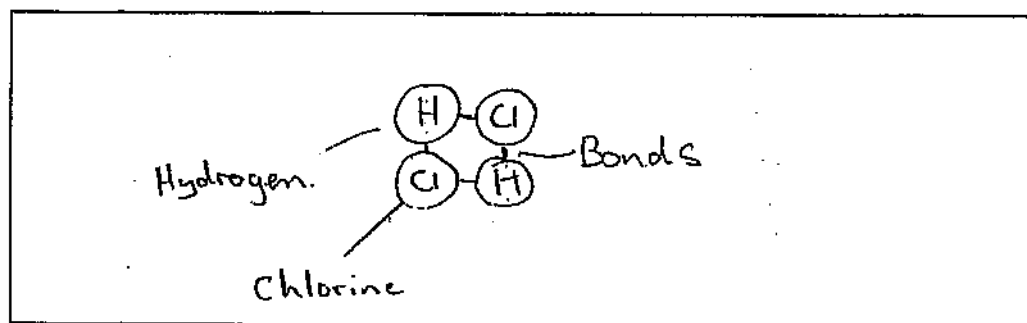
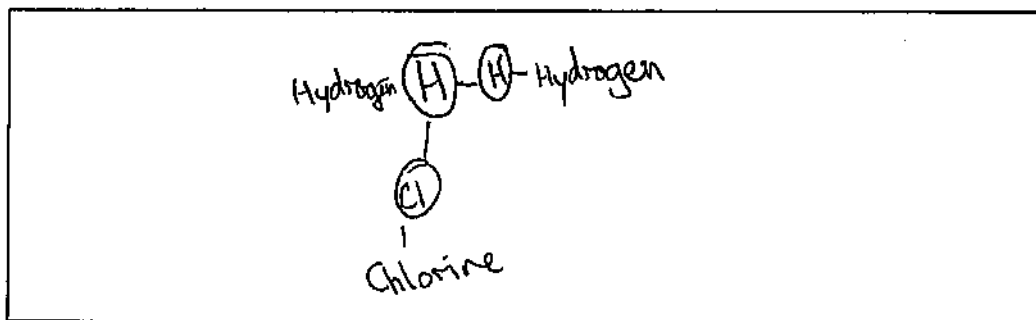


Figure 4-9 Work sample from Student 5 for Question 2

- Interviewer:** In question 2 can you tell me why did you draw your molecule like this?
- Student 5:** Because, its got 2 in front of HCl.
- Interviewer:** OK, but why did you link the atoms the way you did?
- Student 5:** What do you mean?
- Interviewer:** Why did you join the atoms with lines like this [pointing to written response] ?
- Student 5:** Hydrogen is joined to chlorine in HCl and because there is a two out front of the "H", this means that there are two of these together?
- Interviewer:** Sorry, I don't quite understand. Two of what together?
- Student 5:** Two molecules of HCl together.

*Figure 4-10 Pretest interview A with Student 5*

Student 7 drew a molecule structure with two hydrogen atoms and one chlorine. This was consistent with his response to Question 1b and his responses to verbal questioning during the interview.



*Figure 4-11 Work sample from Student 7 for Question 2*

In summary, analysis indicated that all students were aware that the coefficient '2' in front of the symbol for hydrogen chloride (2 HCl) meant that there were multiple quantities of something, however, the understanding of the specific entity existing in multiple quantities varied between students. Of all participants surveyed on the pretest, most considered the coefficient to mean two quantities of HCl, ie. two molecules of HCl (although only two students specifically used the term "molecule"). Of the remaining

students, two applied the coefficient to both the hydrogen and chlorine atoms, but considered that all atoms were separate and did not recognise the formation of any molecular structure. Another student applied the coefficient to both elements, but considered the particles formed an aggregate of bonded particles. The remaining student only applied the coefficient to the first chemical symbol. This student, when interviewed, showed that he was unable to differentiate between the numerical coefficients and the numerical subscripts. This suggests that the student was not considering the formulae of the substance to represent a molecular entity or particle arrangement.

After interaction with the IMM software, all students drew chemically correct molecular representations for both Question 2a and 2b on the posttest, with the exception of Student 7 who maintained his viewpoint regarding the coefficient '2' in front of the formula to mean "a particle with two hydrogens and one chlorine".

### **Discussion and Assertions**

These results indicate that all students had a sound knowledge of the symbols for nitrogen, hydrogen, chlorine and carbon. These chemical symbols were among those studied in Year 9 Chemistry at this school and were revised in the first term of their Year 10 Chemistry program. All students were able to interpret the symbol and provide the name of the represented element. This ability was considered to be well-developed on both pre- and posttests. This evidence permits the following assertion (4.1) to be made.

#### *Assertion 4.1*

<i>Students' knowledge of the chemical symbols for nitrogen, hydrogen, chlorine and carbon were well developed.</i>
---------------------------------------------------------------------------------------------------------------------

In many cases student responses showed no understanding of the molecular nature of the aggregate of particles. Participants' knowledge of the meaning of chemical formulae was initially limited to a basic awareness of the particles involved, but did not extend to the

formulation of molecules. Instead their responses suggested that the particles were merely a collective, with no internal relationship, spatial or otherwise. Student 7 for example, illustrated the alternative conception, in which  $2\text{HCl}$  is the same as  $\text{H}_2\text{Cl}$ . This finding supports the work of Savoy (1988) and Schmidt (1984) and Lazonby, Morris and Waddington (1982). The consideration of formulas to represent merely a collective of atoms was further supported in this study, by students' incorrect use of various chemical terms, such as atom, molecule, and compound. These terms were often used incorrectly and at times without a true understanding of the significance of the meaning of the term, an observation that was confirmed by interviews. Other students were aware that they did not fully appreciate the significance of the chemical terms and tried to avoid confusion and specificity by using the term 'particle'. Generic terms, such as 'particle' are often used in their Chemistry courses when the teacher does not want students to get tied up in the meaning of specific terms, when attempting to achieve a particular lesson objective.

These conclusions support a study by Ben-Zvi et al. (1988), in which they examined some of the conceptual demands placed on chemistry students. The authors stated that "the root of many difficulties that beginning chemistry students have appears to be deficient understanding of the very basic concepts of the atomic model and how it is used to explain macroscopic properties and the laws of chemistry" (p. 89). These authors further suggest that the reason why the study of chemistry is so difficult is that "...students usually do not have enough time to 'get used' to function at the atomic-molecular level and are asked very early in their studies, to think in terms of moles of particles" (p. 90). This expectation that students should move very quickly from one level of description to another is supported by an examination of the structure and design of many contemporary textbooks. These authors argue that teachers, courses and textbooks often require students to make conceptual jumps between three levels of description: atomic-molecular level, multi-atomic level and the macroscopic level, and that this poses some difficulty for novices or students. This work was further supported by Johnstone (1991) who defined three levels of thought: sub-microscopic, macroscopic and symbolic. In this work, Johnstone highlighted that experienced chemists and chemical educators had the ability to operate across these levels

of thought and further concluded that many students experienced difficulty in moving from one level of thought to another.

Garnett et al. (1995) stated, "students' inability to visualise the particulate/submicroscopic nature of matter represents a major area of difficulty in developing a sound conceptual understanding of chemistry" (p. 90). This statement supported the suggestion from Nakhleh (1992) that there are profound misconceptions in the minds of many students about the particulate and kinetic nature of matter. Garnett et al. also reported that Herron (1978) believed that such difficulties were due to the abstract, unobservable and the particulate basis of chemistry, which were recognised within the Piagetian epistemological framework.

This suggests that the difficulties that students experienced with the concept of molecules, coefficients in front of molecular formulae and the meaning of chemical formulae, may stem from the difficulty in moving from a simple interpretation of the symbols and atoms involved, to a consideration of the complex structure and bonding that is contained within the notion of a molecule. The difficulties experienced by students in this situation can often result in a range of alternative conceptions that are the result of students attempting to construct new meaning using their present conceptual framework to interpret new information in a way that the learner understands. Such alternative conceptions can result in poorly understood or defined terms, such as the atom, molecule, compound or particles. Novak (1988) and Nussbaum and Novick (1982) stated that such alternative conceptions may be highly resistant to change. This suggests that unless teaching and learning programs explicitly address the conceptual steps involved in moving from one level of description to another, then student generated alternative conceptions may hinder the conceptual progress of the student.

The evidence from this study permits the following assertions (4.2 – 4.4) to be made.



***Assertion 4.2***

***Students' knowledge of the meaning of chemical formulae was limited to a basic awareness of the number of particles involved, but did not extend to the formulation of molecules in pretest conditions.***

***Assertion 4.3***

***Students' initial use of chemical terminology (atom, molecule and compound) was haphazard and undefined.***

***Assertion 4.4***

***Students were aware that coefficients indicated multiple amounts of atoms but did not extend to multiple groups of atoms (molecules).***

On the posttest, students' correct use of these specific chemical terms (atom, molecule and compound) had improved substantially. They were more confident in responses under interview conditions and in general were more accurate and articulate in their descriptions, when attempting to explain their answers and their understanding of chemical formulae, than in the pretest. This evidence suggests that student interaction with the IMM software resulted in a greater understanding of the structure of molecules, which led to improvements in the interpretation of chemical formulae and in the use of chemical terminology.

This assertion supports the suggestion from Garnett et al. (1994) that modern multimedia technology offers exciting possibilities to provide students with opportunities to observe through simulation the particulate/submicroscopic nature of matter in its various states and forms and the interactions and processes underlying physical and chemical change. These possibilities exist due to the unique capabilities of this dynamic medium to

display concrete models that can, according to Herron (1978) help students visualise the particulate nature of matter.

Despite the many instructional advantages to be gained from the use of animations in learning sequences, Reiber (1990) reported that many applications tended to under-use this resource. The use of animations in science education to help illustrate scientific concepts and processes was investigated by several researchers and found to have particular advantages (Mayer & Gallini, 1990; di Sessa, 1982; White, 1984). The IMM software utilised in this research combined verbal, written and animated cues in the instructional process. Mayer and Anderson (1992), suggested that the value from such media in instructional settings is maximised when they are used in a contiguous rather than a separate fashion. This belief supports the use of various cues in an IMM instructional setting and is also supported by the work of Paivio (1979) on dual coding and its additive effect on memory.

The evidence from this study permits the following assertion (4.5) to be made.

*Assertion 4.5*

*Students' understanding of chemical formulae, and use of chemical terminology was enhanced by interaction with the IMM software.*

**Representations of the Particulate Nature of Matter**

Further analysis of Question 2 indicated that all student participants represented atoms as spheres, which upon interview was defined by all, as "the whole atom .... nuclei and electron clouds" with the exception of Students 1 and 5 who defined the sphere as the "nucleus of the atom". There was some inconsistency in the representation of the size of the elements involved in the substances with some students representing the relative sizes of the atoms correctly, others incorrectly and some not considering the relative sizes at all.

This is illustrated with separate pre- and posttest interviews conducted with Students 3, 5 and 8.

**Interviewer:** Why did you draw all of the atoms the same size?  
**Student 3:** Why not? They are all atoms and all the same size.

*Figure 4-12 Pretest interview A with Student 3*

**Interviewer:** Why did you draw the nitrogen atom bigger than the hydrogen atom here [Question 2A] and the hydrogen atom bigger than the chlorine atom here [Question 2B]?  
**Student 3:** Atoms are different sizes.  
**Interviewer:** Why?  
**Student 3:** Because they come from different elements.  
**Interviewer:** What makes the atoms of some elements bigger or smaller than others?  
**Student 3:** Don't know  
**Interviewer:** How do these atoms differ?  
**Student 3:** You mean ... different number of protons, electrons and neutrons?  
**Interviewer:** Do you think that this would make atoms be different in size?  
**Student 3:** Don't know ... don't think so ... they [protons, neutrons and electrons] are too small to make a difference.

*Figure 4-13 Posttest interview A with Student 3*

**Interviewer:** Why did you draw all of the atoms the same size?  
**Student 5:** Don't know ... just did it.  
**Interviewer:** Can you think of a reason why they should be the same size or why they shouldn't?  
**Student 5:** No ... they are all very small. Atoms are pretty close to being the same size.  
**Interviewer:** What might make them slightly different in size?  
**Student 5:** Depends what they are doing ... what reaction ... or ... atoms they are with I guess.

*Figure 4-14 Pretest interview B with Student 5*

**Interviewer:** [ ... ] In the diagram why did you draw the nitrogen atom bigger than the hydrogen atom?

**Student 5:** Because it is bigger than hydrogen.

**Interviewer:** Why do you think that it is bigger?

**Student 5:** The computer program always showed hydrogen to be smaller than all other atoms.

**Interviewer:** Do you know why?

**Student 5:** Not sure ... but when it showed the graphics ... the ball things ... umm atoms were all different sizes and hydrogen was the smallest. Some of them even changed size during a reaction.

**Interviewer:** Why do you think that they did that?

**Student 5:** Was it because they lost electrons and got smaller in size ... they lost ... umm ... valence electrons?

**Interviewer:** Would that make atoms smaller?

**Student 5:** Definitely ... losing outer shell of electrons gives them a smaller size.

**Interviewer:** Why did you draw the hydrogen and the chlorine as the same size in the next question [Question 2b]?

**Student 5:** I forgot about it ... I just wanted to get the question right.

**Interviewer:** Which one do you think is bigger, hydrogen or chlorine?

**Student 5:** Chlorine.

*Figure 4-15 Posttest interview A with Student 5*

**Interviewer:** Why did you draw the atoms of nitrogen, hydrogen and chlorine different sizes?

**Student 8:** Atoms of elements are different in size ... depending upon the number of electrons in orbits around the nucleus.

*Figure 4-16 Pretest interview A with Student 8*  
*No posttest interview was conducted with this Student on this matter.*

These interview excerpts illustrate that both Student 3 and 5 initially considered all atoms to be the same size, however, after interaction with the IMM software these students stated that different atoms were indeed different sizes. Student 3 however, was unable to provide any justification for this statement, but Student 5 stated that he noticed the different atoms were different in size in the IMM software. This student also noted that the representations of atoms in the software changed size during a chemical reaction and then

postulated that this may have been the result of either losing or gaining valence electrons. Finally, Student 8 displayed an indepth appreciation of the factors affecting atomic radii, prior to interaction with the IMM software.

Another interesting observation from the analysis of pre- versus posttest responses was that many of the structures drawn in the pretest questions were represented by 'ball and stick models', whereas in the posttest they were drawn as 'space-filling models'. This observation was further investigated by interview with Students 2, 5 and 10. In this series of interviews students were shown their responses on the pre- and posttests.

<b>Interviewer:</b>	The first time you answered this question [question 2] you drew the atoms in the ammonia molecule as balls connected by these lines. However, the second time you answered the question you drew the atoms very close to each other. Why?
<b>Student 2:</b>	I used to think that things like ammonia had atoms far apart ... and that they were joined by electrons between them.
<b>Interviewer:</b>	... and now?
<b>Student 2:</b>	I still think that they are held together .. but that they [the atoms] are closer than I thought ... does it really matter anyway?
<b>Interviewer:</b>	What do you mean?
<b>Student 2:</b>	Aren't we only drawing a model ... they don't really look like that?
<b>Interviewer:</b>	What do you think that they look like?
<b>Student 2:</b>	Don't know ... but I don't think that atoms look like little balls ... it's just easy for us to imagine them that way.

*Figure 4-17 Posttest interview A with Student 2*

**Interviewer:** The first time you answered this question [question 2] you drew the atoms in the ammonia molecule as balls connected by these lines. However, the second time you answered the question you drew the atoms very close to each other. Why?

**Student 5:** I used to think that the balls [representations of atoms] were the nuclei of atoms ...

**Interviewer:** ... and now.

**Student 5:** perhaps they mean the furthest out point ... size of the atom ... where the valence electrons are.

**Interviewer:** How are they held together or bonded together.

**Student 5:** still by sharing electrons ... but electrons are smaller than atoms and that's why we shouldn't show the bond between atoms.

*Figure 4-18 Posttest interview B with Student 5*

**Interviewer:** The first time you answered this question [question 2] you drew the atoms in the ammonia molecule as balls connected by these lines. However, the second time you answered the question you drew the atoms very close to each other. Why?

**Student 10:** Didn't know that I did that.

**Interviewer:** Can you think of a reason why?

**Student 10:** No.

**Interviewer:** Have you seen molecules drawn like any one of these in the past?

**Student 10:** Yes ... you always draw molecules like this [pointing to the pretest] but the computer model showed them like this [pointing to the posttest]. Which one is right?

**Interviewer:** Do we have to have only one as correct?

**Student 10:** Yeah ... did you get it wrong?

*Figure 4-19 Posttest interview B with Student 10*

These data indicate that students' representation of the particulate nature of matter was altered as a result of their interaction with the IMM software. Initially, all students represented atoms as spheres, which upon interview was defined by all as "the whole atom ... nuclei and electrons", except Students 1 and 5, who defined the sphere as the nucleus of the atom. Further analysis indicated that there was much inconsistency in the size of the structures drawn by students, with a few considering size (although sometimes incorrectly)

and the majority giving it no consideration in their responses. On the posttest, all students considered the size of the particles prior to drawing their representation, however, although considered, some students failed to represent the size of atoms correctly relative to the size of other atoms. In addition, some students revealed during the interview that they drew the particles in relative sizes because "the computer program always showed hydrogen to be smaller than the others". This indicates that the computer simulation was successful in indicating the relative sizes of atoms, but did not provide the explanation as to why some particles are bigger than others. This concept was understood by some, but not by all students.

### **Discussion and Assertions**

The responses from students relating to the relative sizes of atoms are not surprising in light of the assertions of Ben-Zvi et al. (1996) who have suggested that "many students hold a wrong picture of the nature of the atom and the structure of compounds" (p. 89). These authors further state that "even a superficial overview of the development of the atomic theory is enough to convince us that the concepts involved are very difficult" (p. 89). These authors also note and remind us that students "cannot avoid using the word atom right from the first lesson in chemistry and even prior to it" (p. 89). These statements then beg the question that if students are using such terminology prior to formal introduction to atomic models, then what do they consider an atom to look like?

Garnett et al. (1995) reviewed a number of studies on alternative conceptions on a range of topics, including the particulate nature of matter. In this review, these authors identified and collated a number of alternative conceptions, which they concluded indicated that "...the development of a particulate model of matter which includes an understanding of the nature and spacing of particles and how these are related to the macroscopic properties of substances, poses significant difficulties for many students" (p. 74).

The tendency for students to retain a superficial image of the atom, even after formal instruction may be attributed to students attempting to consider these individual particles macroscopically instead of at the submicroscopic level. This tendency has been

well documented by Andersson (1990) and Griffiths and Preston (1992). These multilevel considerations are also well documented and supported by the work and viewpoints of Johnstone (1991). While it is widely accepted that such concepts can be examined at varying levels, it is also important to note that the ability to do so depends partly on the students' cognitive development. This statement is supported by the work of Renstrom, Andersson and Marton (1990) in which they proposed that students' conceptions of matter developed from a 'homogeneous view', through 'substance and particle units' prior to developing an understanding on the basis of 'systems of particles'. Such development may be enhanced through the use of the IMM software, *Balancing and Interpreting Chemical Equations*. This assertion supports the work of Garnett et al. (1995) and that of Zietsman and Hewson (1986) who have indicated that computer based instructional materials, based on a conceptual change pedagogy can facilitate improved student learning. Further, Garnett et al. (1994) postulated that "this instruction is most likely to be successful when it provides visual concrete representations of unobservable processes and events, and causes students to reflect on their present conceptions. Interactive multimedia materials are eminently suited to the simulation of chemical processes using dynamic graphical representations of molecular interactions" (p. 31).

Another interesting change in students' representation of atoms and molecules as a result of interaction with the IMM software was the change from 'ball and stick' structures to that of 'space filling' models. This aspect of student representation was further investigated by interview with three students, which identified the following independent reasons for their representations:

**Student 2:** This student explained that both representations are simply models and that perhaps the atoms are closer together than the 'ball and stick' model suggests. This student clearly stated that such models are only used to assist us to understand and imagine the structure and it does not really matter which one we use.



**Student 5:** This student had cognitively restructured his representation of atom from one in which the spheres represented only the nuclei to one in which the sphere now represented the furthest point of the atom (where the valence electrons are). This student indicated that the process of bonding involves electron sharing and that since electrons are so small and attracted to both nuclei of atoms involved, the bond should not be represented by a long line as in the 'ball and stick' model.

**Student 10:** This student identified his reasons for initially drawing molecules using the 'ball and stick' notation as a result of previous experience in his chemistry class.

This was confirmed by examining lesson plans, notes and handout prepared by the teacher, in which all molecular representations were of this nature. The student explained that he changed his way of drawing molecules because the "computer model showed them like this". When asked whether both ways of drawing molecules were acceptable, the student stated that only one could be correct and then suggested that maybe his teacher had drawn them incorrectly. This illustrated a previously unconsidered power of the IMM software in developing student understanding over experience with standard teaching practice. That is, that students may tend to identify and accept multimedia representations of the particulate nature of matter as being more accurate than those illustrated by conventional means of learning, simply because it was illustrated on a computer. This dilemma may require further research and investigation.

The evidence from this study permits the development of the following assertion (4.6):

***Assertion 4.6***

***Students' representation of atoms and molecules changed from 'ball and stick models' to 'space filling models' through interaction with the IMM software.***

### Balancing Chemical Equations

In Question 3 students were asked to balance a series of four chemical equations. Each of the equations had a similar logical structure although they were listed in order of increasing M demand as defined by Niaz and Lawson (1985). The results for each student on these tasks are summarised in Table 4-1.

Question 3	Balance the following equations.					
a)	Mg	+	F <sub>2</sub>	→	MgF <sub>2</sub>	
b)	Na	+	Cl <sub>2</sub>	→	NaCl	
c)	Fe	+	Cl <sub>2</sub>	→	FeCl <sub>3</sub>	
d)	Al	+	O <sub>2</sub>	→	Al <sub>2</sub> O <sub>3</sub>	

*Figure 4-20 Question 3 from the pre and posttests*

In general, students were able to correctly balance the chemical equations, with the exception of Students 7 and 9 who struggled on the pretest. On the posttest, Student 9 correctly balanced all equations and Student 7 only the first two. This sequence of failure and success is consistent with the increasing M demand of the assigned tasks (Pascual-Leone, 1970). On the pretest, Students 7 and 9 attempted to balance equations by manipulating the formula of the species involved in the equation. This suggests that these students did not appreciate that subscripts are there to indicate groupings of atoms. This is illustrated by the following equations (Figure 4-21, 4-22) written by these students.

**Table 4-1:**  
*Students' success in balancing chemical equations in Question 3 of pre- and posttests.*

<b>Students</b>	<b>Question 1</b>	<b>Question 2</b>	<b>Question 3</b>	<b>Question 4</b>
<b>1 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>2 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>3 pretest</b>	√	√	√	X
<b>posttest</b>	√	√	√	√
<b>4 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>5 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>6 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>7 pretest</b>	X	X	X	X
<b>posttest</b>	√	√	X	X
<b>8 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√
<b>9 pretest</b>	X	X	X	X
<b>posttest</b>	√	√	√	√
<b>10 pretest</b>	√	√	√	√
<b>posttest</b>	√	√	√	√

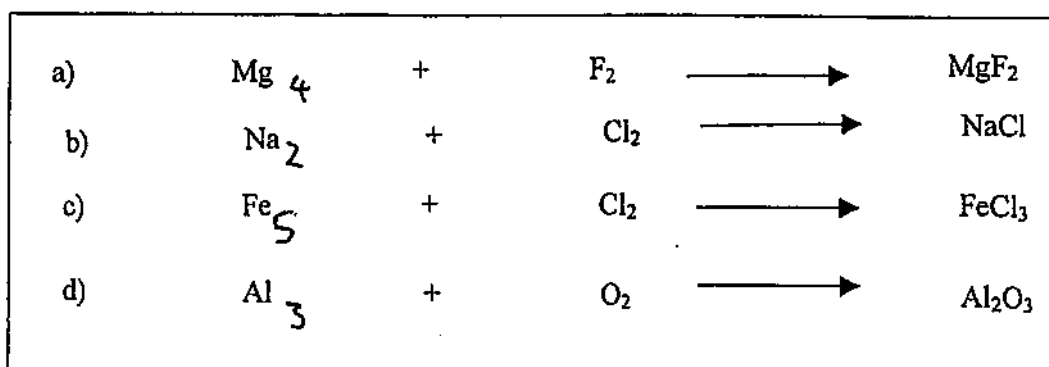


Figure 4-21 Work sample from Student 7 for Question 3 (Pretest)

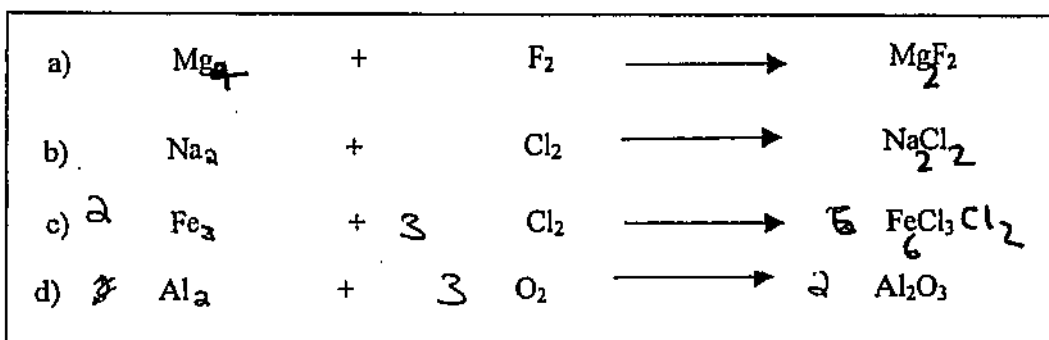


Figure 4-22 Work sample from Student 9 for Question 3 (Pretest)

Student reasoning for such responses was investigated by interview. An excerpt from an interview after the pretest with Student 7 is provided.

- Interviewer:** What was the purpose of question 3?  
**Student 7:** To get us to balance the equation.  
**Interviewer:** Can you explain what you do to balance the equation?  
**Student 7:** ... You try to make all atoms equal.  
**Interviewer:** What do you mean "make the atoms equal"?  
**Student 7:** You make each atom have the same on either side of the arrow.  
**Interviewer:** Why do you do that?  
**Student 7:** ...cause that's what we were told to do!  
**Interviewer:** OK but why do you think that?  
**Student 7:** Don't know ... you just have to.  
**Interviewer:** Can you explain why you put numbers where you did in the equation?

<b>Student:</b>	... to balance the atoms.
<b>Interviewer:</b>	Could you place those numbers in front of the symbols of the elements?
<b>Student 7:</b>	If you want to ... it doesn't make a difference.

*Figure 4-23 Pretest interview B with Student 7*

This excerpt indicates that the student had little or no appreciation as to why all chemical equations need to be balanced, but was aware of the need or requirement to ensure that the number of each type atom were the same on both sides of the equation.

Following interaction with the IMM software the student was able to correctly balance the two, less demanding equations but when confronted by the two, more challenging tasks reverted to the previous incorrect conception in which the subscripts in the molecular formulae were manipulated and altered in an attempt to balance the chemical equation. This is in contrast to Student 9 who had a similar conception on the pretest and which was altered as a result of interaction with the IMM software.

<b>Interviewer:</b>	If we look at your responses on this initial test compared to the last one for question 3, your thoughts on balancing equations seem different.
<b>Student 9:</b>	How?
<b>Interviewer:</b>	Look at your answers – they are different.
<b>Student 9:</b>	I didn't realise that the subscript was part of the formula.
<b>Interviewer:</b>	What do you mean?
<b>Student 9:</b>	If you put a subscript down, it means that there a that number of atoms joined together not just more of them.
<b>Interviewer:</b>	Can you give me an example?
<b>Student 9:</b>	umm ... $\text{Cl}_2$ is two fluorine atoms ... no chlorine atoms joined together but a 2 in front means two separate chlorine atoms.

*Figure 4-24 Posttest interview B with Student 7*

In Questions 4 and 5 students were asked to explain their understanding of a balanced chemical reaction through symbolic and pictorial representations. The questions were designed to highlight misconceptions of the particulate nature of matter and also to identify consistency in student responses in the two forms of representations. The equation:

$2\text{Al} + 3\text{Br}_2 \rightarrow 2\text{AlBr}_3$  was specifically selected to assess student understanding of the particulate nature of metals and molecules.

Question 4:	Explain what the following equation represents in terms of the numbers and types of particles involved. $2\text{Al} + 3\text{Br}_2 \rightarrow 2\text{AlBr}_3$
Question 5:	Draw diagrams for the following equation to represent the reactant and product substances in the reaction, at the particulate level. $2\text{Al} + 3\text{Br}_2 \rightarrow 2\text{AlBr}_3$

Figure 4-25 Question 4 and 5 from pre and posttests

Student responses illustrating their understanding of the symbolic unit of  $3\text{Br}_2$  in both pretest and posttest conditions are summarised in Table 4-2.

Table 4-2:  
Comparison of representations of  $3\text{Br}_2$  on the pre- and posttests

Student	Representation on Pretest	Representation on Posttest
1	3 x bromide	3 molecules of $\text{Br}_2$
2	6 bromine atoms	3 molecules of $\text{Br}_2$
3	6 bromine atoms	3 molecules of $\text{Br}_2$
4	3 x bromine molecules	3 molecules of $\text{Br}_2$
5	Only identified $\text{Br}_2$ as bromine	3 molecules of $\text{Br}_2$
6	Only identified $\text{Br}_2$ as bromine	3 molecules of $\text{Br}_2$
7	6 x barium atoms	6 x bromine atoms all bonded together
8	Only identified $\text{Br}_2$ as bromine	3 molecules of $\text{Br}_2$
9	6 bromine particles	3 molecules of $\text{Br}_2$
10	3 molecules of $\text{Br}_2$	3 molecules of $\text{Br}_2$

The following student work samples illustrate the above representations:

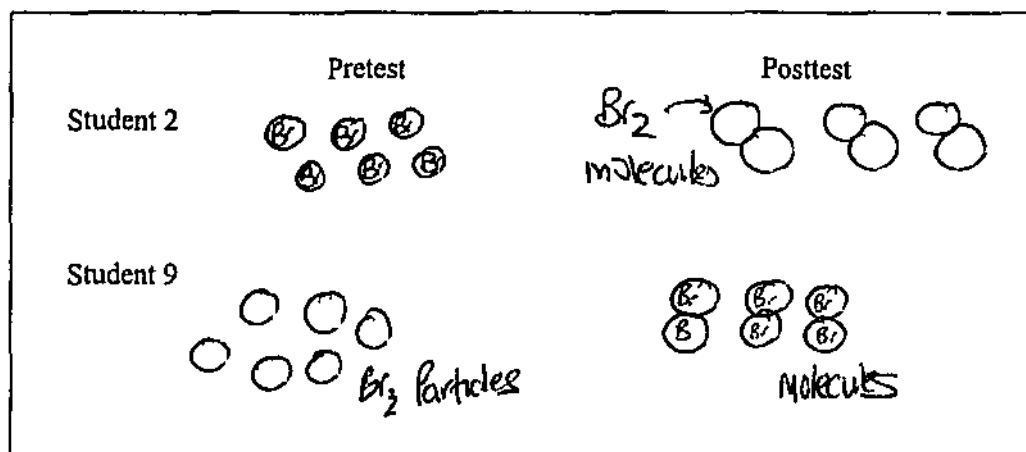


Figure 4-26 Work samples from Students 2 and 9 for Question 5

The comparisons indicate that there was a substantial improvement in student understanding of the symbolic representation in question. In general, student answers were more developed and descriptive in the posttest as a result of their interaction with the IMM software. This assertion was supported in an interview with student 8.

- |                     |                                                                                                                                             |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Interviewer:</b> | Why did you refer to $3\text{Br}_2$ as only bromine in the initial test and in the second refer to it as three molecules of $\text{Br}_2$ . |
| <b>Student 8:</b>   | I don't know ... I knew that there were three of them before ... I just didn't write it.                                                    |
| <b>Interviewer:</b> | Can you think of a reason why that happened?                                                                                                |
| <b>Student 8:</b>   | Not really ... I just felt that I knew more the last time. I knew I could get the questions right ... so I wrote down what I knew.          |

Figure 4-27 Posttest interview A with Student 8

Student responses illustrating their understanding of the symbolic unit of  $2 \text{ AlBr}_3$  in both pretest and posttest conditions are summarised in Table 4-3.

Table 4-3:  
*Comparison of representations of  $2 \text{ AlBr}_3$  on the pre- and posttests*

Student	Representation on Pretest	Representation on Posttest
1	2 moles of aluminium bromine	2 molecules of $\text{AlBr}_3$
2	aggregate of 2Al and 6Br atoms	2 molecules of $\text{AlBr}_3$
3	2 molecules of $\text{AlBr}_3$	2 molecules of $\text{AlBr}_3$
4	2 molecules of $\text{AlBr}_3$ bonded	2 molecules of $\text{AlBr}_3$
5	aggregate of 2Al and 6Br atoms	2 molecules of $\text{AlBr}_3$
6	aggregate of 2Al and 6Br atoms	2 molecules of $\text{AlBr}_3$
7	aggregate of 2Al and 6Br atoms	aggregate of 2Al and 6Br atoms
8	aggregate of 2Al and 6Br atoms	2 molecules of $\text{AlBr}_3$
9	2 molecules of $\text{AlBr}_3$	2 molecules of $\text{AlBr}_3$
10	No pictorial representation although stated that there were 2 $\text{AlBr}_3$ particles	2 molecules of $\text{AlBr}_3$



The following student work samples illustrate the above representations:

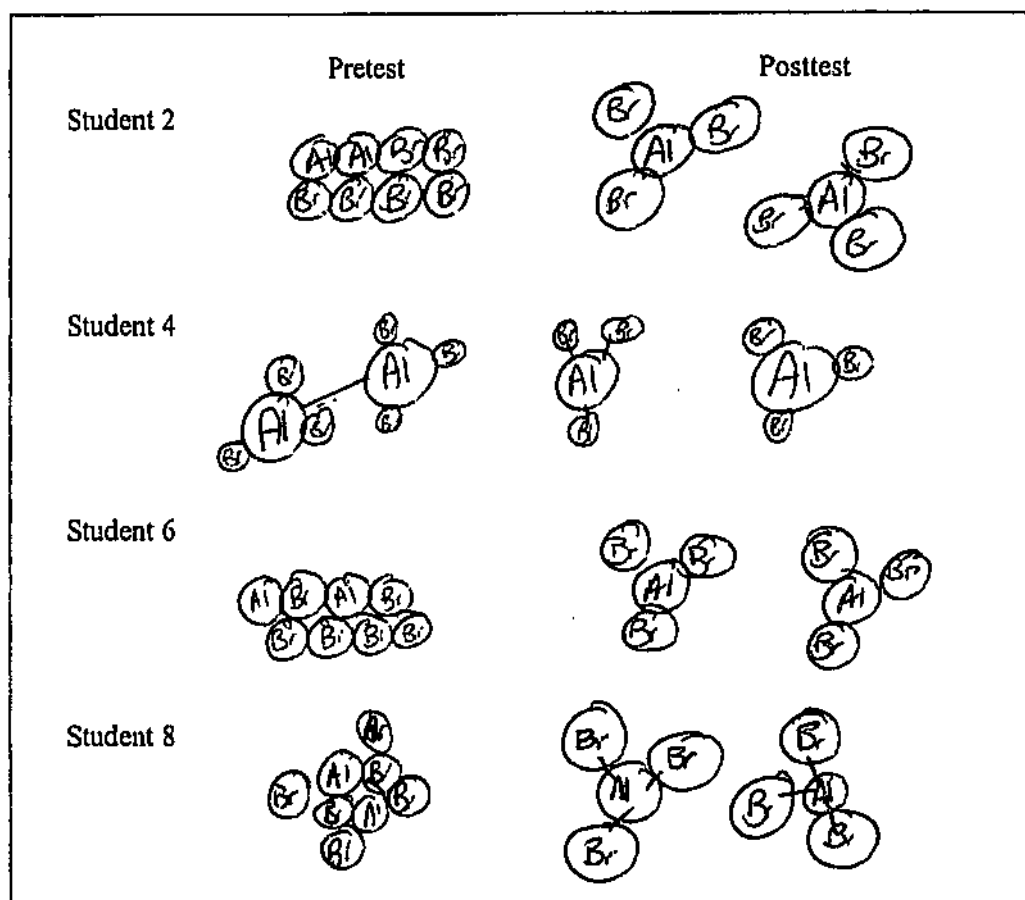


Figure 4-28 Work samples from Students 2, 4, 6 and 8 for Question 5

The symbolic representation of aluminium in the equation ( $2\text{Al}$ ) was correctly identified by all students as being two aluminium atoms. The pictorial representations from students were either drawn as two separate spheres or two spheres close together. In terms of the chemistry in question, both representations are accurate depending upon the intended meaning. This was illustrated by Student 8 during interview.

**Interviewer:** Why did you draw the Al particles together in the first and separate in the second?

**Student 8:** I didn't realise that I had done that.

**Interviewer:** Why would you draw them these two ways?

**Student 8:** You could draw them together because Al is a metal and all particles are closely packed, but looking at it now it looks like a molecule ... so you could draw them separate because they react as atoms.

*Figure 4-29 Posttest interview B with Student 8*

In summary, students were required to balance a series of four chemical equations, which contained a similar logical structure but differed in their M demand (Pascual-Leone, 1970). The results for the tasks and the sequence of failure and success indicate that students could balance chemical equations prior to using the IMM software. This implies that the students had the required mathematical ability, M capacity for information processing, experience and the ability to disembed relevant information (field dependency) to balance chemical equations prior to using the IMM software. It should also be noted that observations made by the Researcher indicate that the process used by students to balance the equations in both pre- and posttests was trial and error. This was evident when listening to several students who 'talked aloud' during the problem-solving task and by viewing the various numeric alterations made on their tests. This is illustrated by the following excerpt from an audio tape and student work sample.

**Student 2:** One Mg on left and one on right ...two F's and two F's (Question 3a complete). One Na and one Na ...two Cl and one ... put two in front of NaCl ... done ...put two Na on left (Question 3b complete). Put two Cl<sub>2</sub>'s ... two times two ...four. Put three Cl<sub>2</sub>'s ... six ...two FeCl's and two in front of Fe on left (Question 3c complete). Need ... [unable to decipher] ... oxygen ... 3 in front of ...three times three is nine ... two times equals nine... [rubs out three] two Al<sub>2</sub>O<sub>3</sub>'s and six oxygens is three O<sub>2</sub>'s and two Al's.

*Figure 4-30 Excerpt from an audio recording of Student 2*

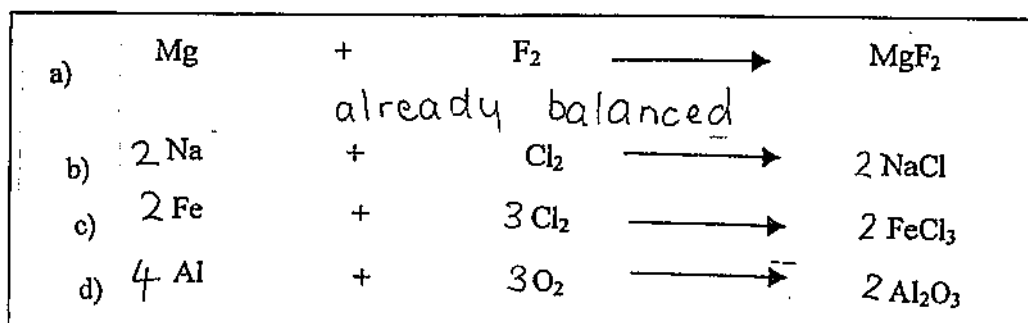


Figure 4-31 Work sample from Student 4 for Question 3

### Discussion and Assertions

Although the majority of students were able to correctly balance the chemical equations on the pretest, they appeared to have little understanding of the particulate nature of the matter concerned. When asked to represent the structure of 3Br<sub>2</sub>, only Students 4 and 10 correctly drew three molecules of Br<sub>2</sub>. Students 2, 3, 7 and 9 referred to the representation as either 6 bromine atoms or particles. These students did not illustrate the molecular nature of bromine and also showed an inconsistent use of associated chemical terms. Student 1 indicated that 3Br<sub>2</sub> was actually 3 x bromides, whereas Students 5, 6 and 8 indicated that this representation was simply bromine. On the posttest, there was a dramatic improvement in both the representation of the structure and in the use of the associated chemical terms, with all but one student responding correctly. A similar pattern of responses was noted with the illustration and representation of AlBr<sub>3</sub>, as shown in Table 4-3.

This suggests that the students were capable of mathematically balancing the equation, without understanding the particulate nature of the species involved prior to using the IMM software. The IMM software improved students' understandings of the particulate nature of matter and the therefore may have also improved their understanding of the processes of balancing chemical equations.

Many studies have previously investigated student's understanding of balancing chemical equations (Ben-Zvi et al. 1987; Garnett, Hackling, Vogiatzakis & Wallace, 1992; Yaroch, 1985). These studies identified a range of alternative conceptions that were categorised and listed by Garnett, Hackling & Oliver (1995). These alternative conceptions are listed below in Table 4-4.

Table 4-4

*Students' misconceptions: Balancing and interpreting chemical equations (Garnett, Hackling & Oliver (1995): Table 2, p. 29)*

Student misconceptions
<ol style="list-style-type: none"> <li>1. Subscripts in formulas are numbers used in balancing equations (and do not represent atomic groupings.</li> <li>2. Equation coefficients are numbers used to mechanically balance equations (and do not represent the relative numbers of species reacting or being produced in chemical reactions).</li> <li>3. Chemical equations do not represent chemical reactions at a particulate level.</li> <li>4. Chemical equations do not represent dynamic processes in which particles/ molecules react with one another to produce new particles/ molecules by rearrangement of the atoms.</li> </ol>

The students in this study, in general, showed an ability to mathematically balance a series of chemical equations that had a similar logical structure, but increased in their M demand, as defined by Niaz and Lawson (1985). These students however, experienced difficulty in drawing diagrammatic representations of equations and many showed a lack of understanding of the different use of subscripts in formulae and coefficients in chemical equations. These assertions support the work of Garnett et al. (1995), in which they stated that "it seems apparent that many students lack a conceptual understanding of the submicroscopic particulate nature of matter and the changes represented by chemical equations" (p. 30). These authors also stated "many students' ability to balance and understand chemical equations is severely limited by their lack of understanding of the submicroscopic particulate nature of matter and their inability to visualise the dynamic process of a reaction on a particulate level" (p. 30).

If the ability to visualise, understand and interpret the particulate nature of matter is accepted as a necessary to assist students balance and interpret chemical equations, then it is likely that these difficulties are based on the abstract and unobservable nature of chemistry as described by Herron (1978). Given the nature of chemistry and the work of researchers such as Gabel and Sherwood (1980), Garnett, Tobin and Swingler (1985), and Herron (1978), who have promoted the use of concrete models to assist students develop an understanding of the particulate nature of matter, it appears probable that IMM technology may have the potential to assist students in this area. In this study, students were better able to both balance chemical equations and represent the particulate nature of matter after interaction with the IMM software. This suggests that the contained animations may have been appropriate models to assist and promote student development.

The evidence from this study permits the following assertions (4.7 - 4.9) to be made.

*Assertion 4.7*

*The majority of students, prior to interaction with the IMM software could mathematically manage the process of balancing equations, but did not understand the particulate nature of matter implied by such a process.*

*Assertion 4.8*

*Most students had the ability to overcome the M demand of the task of balancing chemical equations.*

**Assertion 4.9**

*Student interaction with the IMM software resulted in significant changes in the manner in which they viewed and considered the particulate nature of matter.*

**Chapter Summary**

The assertions developed throughout this chapter are summarised below:

- 4.1 *Students' knowledge of the chemical symbols for nitrogen, hydrogen, chlorine and carbon were well developed.*
- 4.2 *Students' knowledge of the meaning of chemical formulae was limited to a basic awareness of the number of particles involved, but did not extend to the formulation of molecules in pretest conditions.*
- 4.3 *Students' initial use of chemical terminology (atom, molecule and compound) was haphazard and undefined.*
- 4.4 *Students were aware that coefficients indicated multiple amounts of atoms but did not extend to multiple groups of atoms (molecules).*
- 4.5 *Students' understanding of chemical formulae, and use of chemical terminology was enhanced by interaction with the IMM software.*
- 4.6 *Students' representation of atoms and molecules changed from 'ball and stick models' to 'space filling models' through interaction with the IMM software.*

- 4.7 *The majority of students, prior to interaction with the IMM software could mathematically manage the process of balancing equations, but did not understand the particulate nature of matter implied by such a process.*
- 4.8 *Most students had the ability to overcome the M demand of the task of balancing chemical equations.*
- 4.9 *Student interaction with the IMM software resulted in significant changes in the manner in which they viewed and considered the particulate nature of matter.*

## **CHAPTER 5**

### **RESULTS AND DISCUSSION**

#### **STUDENTS' UNDERSTANDING OF THE REACTION PROCESS**

This Chapter presents and interprets data related to students' representations and interpretations of what happens during a chemical reaction. Particular attention is paid to the stoichiometric ratio of chemical species involved in the reaction, both in the basic ratio contained in the chemical equation and when multiples of these quantities are present, and also to the concept of limiting reagents. The data were obtained by comparing student responses to Questions 6-12 on both pre- and posttests, which were triangulated with data drawn from videotapes and interviews. Students' understandings of the reaction process are discussed and then several assertions are made related to this theme.

##### **Students' Understanding of Stoichiometric Relationships**

Questions 6 and 7 examined students' ability to read and interpret the presented balanced chemical equation. These questions only assessed their understanding of the basic stoichiometric ratio as shown in the equation. Questions 8 and 9 required students to interpret and apply multiples of the basic stoichiometric ratio in the equation.



Question 6:	How many particles of Al are required to react with 3 particles of Br <sub>2</sub> , in the following equation? $2 \text{ Al} + 3 \text{ Br}_2 \rightarrow 2 \text{ AlBr}_3$
Question 7:	How many particles of C <sub>4</sub> H <sub>10</sub> are required to react with 13 particles of O <sub>2</sub> , in the following equation? $2 \text{ C}_4\text{H}_{10} + 13 \text{ O}_2 \rightarrow 8 \text{ CO}_2 + 10 \text{ H}_2\text{O}$
Question 8:	How many particles of AlBr <sub>3</sub> are produced from the reaction of 4 particles of Al, in the following equation? $2 \text{ Al} + 3 \text{ Br}_2 \rightarrow 2 \text{ AlBr}_3$
Question 9:	How many particles of H <sub>2</sub> O are produced from the reaction of 10 particles of C <sub>4</sub> H <sub>10</sub> , in the following reaction? $2 \text{ C}_4\text{H}_{10} + 13 \text{ O}_2 \rightarrow 8 \text{ CO}_2 + 10 \text{ H}_2\text{O}$

Figure 5-1 Questions 6 - 9 from pre and posttests

Students 1, 8 and 10 were able to correctly read, interpret and respond to the four questions on both pre- and posttests. Of the remaining students, Students 2, 4, 5 and 6, although responding incorrectly on some of the questions in the pretest, were able to respond correctly to all questions during the posttest. The responses of these students will now be considered in more detail.

On the pretest, Students 2, 5 and 9 were able to read the basic ratio as observed in the equation but were unable to apply that ratio when multiple quantities of this ratio were utilised. On the posttest, all students provided correct responses.

Student 3 correctly responded to Questions 6 and 7 on the pretest and incorrectly to Question 8 (Question 9 was not answered). This student's responses on the posttest are very difficult to interpret. On the posttest this student was able to correctly answer Questions 6 and 7 however, his answers to Questions 8 and 9 require greater consideration. In response to Question 8 the student concluded that only two particles of AlBr<sub>3</sub> could be produced from the reaction because the Br<sub>2</sub> was a limiting reagent. Given that the question did not

specifically indicate that the bromine was in excess (an assumption that would be made by a more experienced chemist) I am left to conclude that the student had developed a concept of limiting reagents. This conclusion was further supported by his answer to Question 9, which was of a similar vein.

Student 4 supplied correct responses to Questions 6, 7 and 8 on the pretest however, incorrectly responded to Question 9. Evidence from his working suggests that he was able to use and interpret the basic stoichiometric ratio in the equation and had limited success when multiple quantities of these were being considered. Further, it appears that he was able to consider these multiple quantities when the factor was simple ( $\times 2$ ), but experienced difficulty when the multiplication factor was more complex ( $\times 5$ ). It should be noted that although the two processes have the same logical structure, Question 9 requires greater mathematical process skills. This student was however, able to correctly respond to all questions in the posttest.

On the pretest, Student 6 only responded to Questions 6 and 8. Although some working was evident in Questions 6 and 7, it appears that the student was unable to deduce what was being asked by the task in question. This was compounded by the student's difficulty in understanding the meaning of coefficients in the equation and of subscripts in formulae. This was confirmed by interview.

**Interviewer:** Can you tell me why you put a 6 for your answer in question 6?

**Student 6:** I'm not sure ... there are 6 bromines reacting.

**Interviewer:** Yes you are correct, however, what is the question asking?

**Student 6:** I don't know ... it doesn't make sense.

**Interviewer:** What doesn't?

**Student 6:** How can I tell how many particles will react?

**Interviewer:** Well ... think about what the equation tells us about the reaction ...

**Student 6:** I just don't get it ... it doesn't make sense!

**Interviewer:** Well ... how many Al particles are needed to react?

**Student 6:** two.

**Interviewer:** ... and how many bromine particles are reacting?

**Student 6:** I don't know ... there are 6 there but how can six bromines react with only two aluminiums.

<b>Interviewer:</b>	Each bromine molecule has two bromine atoms and when it reacts with aluminium, it produces two molecules of aluminium bromide.
<b>Student 6:</b>	... but how do we know that they will react ... there are only three bromine atoms there [products]
<b>Interviewer:</b>	Don't worry, if you cannot do the question leave it and do the next one.

*Figure 5-2 Pretest interview A with Student 6*

This student was able to correctly respond to all four questions on the posttest.

Student 7 was unable to correctly answer any of the four questions in either pre- or posttests. In both tests, his responses to Question 6 and 7 were unusual and idiosyncratic. However, his responses to Questions 8 and 9 indicated that he considered only the basic ratio of reacting species in the equation and did not take into account the multiple quantities present. With this in mind, it is difficult to understand why he did not correctly respond to Questions 6 and 7.

### Discussion and Assertions

These data indicate that the majority of students were able to read and interpret the basic stoichiometry in a balanced chemical equation, with all students responding correctly to Questions 6 and 7, with the exception of Students 6 and 7. Student 6 was unable to deduce what was being asked by the question. This was confirmed by interview and was compounded by the student's difficulty in understanding the meaning of coefficients in the equation and that of subscripts in the formulae. As discussed earlier, some students consider that subscripts in formulae are numbers that can be manipulated and altered to balance chemical equations (Garnett et al., 1995). This suggests that the students' ability to learn and correctly respond to questions is affected by his lack of appreciation of the meaning of subscripts, formulae, the particulate nature of matter (the contextual knowledge required by the question) and the student's own ability to read and interpret the question at hand.

The significance of subscripts and coefficients in chemical formulae and the alternative conception that such subscripts can be manipulated and altered to balance an

equation, illustrates fundamental errors in students' understanding of the particulate nature of matter. This significant misunderstanding has been researched and stated by many, including Ben-Zvi et al. (1987); Garnett et al. (1995); Savoy (1988); Lazonby et al. (1982) and Yarroch (1985).

Student 7 was unable to correctly answer Questions 6 and 7 in both the pre- and posttest. Evidence from Questions 8 and 9, in which his responses suggest that he considered the basic ratio of reacting species, and yet did not respond correctly to Questions 6 or 7. This is difficult to interpret and may suggest a lack of motivation or effort, or difficulties in question interpretation.

All but three students experienced difficulty in the application of the basic ratio contained in the balanced equation and answered incorrectly to Questions 8 and 9 on the pretest. This suggests that although many students could read and interpret the stoichiometry in the balanced equation, they had difficulty in its application to multiple quantities. This is further supported by the responses of Student 4, who was able to correctly respond to Question 8, but incorrectly responded to Question 9. Examination of these questions indicates a similar logical structure, but differing M demand due to the increased difficulty of the mathematical relationships involved in the latter question.

Such inability may suggest that the students in the study were considering the numerical coefficients as merely numbers that were mechanically used to complete the mathematical task of balancing the chemical equation. If the task were completed with this mind-set, then it seems probable that students would have shown a lack of understanding in the application of such multiple quantities to simple stoichiometry. Garnett et al. (1995) reported this misconception after reviewing the work of various researchers.

The evidence from this study permits the following assertion (5.1) to be made.

**Assertion 5.1**

*The majority of students were able to read and interpret the basic stoichiometry of an equation, but were unable to apply these relationships to multiple quantities.*

Following use of the IMM software, all students responded correctly to Questions 6 – 9, with the exception of Student 7, who was previously discussed. This suggests that with use of the IMM software there was a significant improvement in student ability to understand and apply stoichiometric relationships. Further analysis of the responses from Student 3 suggests that he considered the concept of limiting reagents in the interpretation of the question. This student's responses suggest that an in-depth appreciation of limiting reagents and reacting quantities had been developed.

Several studies have illustrated that computer-based multimedia can help people learn more information more efficiently than the traditional classroom lecture (Bosco, 1986; Fletcher, 1989; Kulik, Kulik & Cohen 1980). Further Andersson (1986) and Ben-Zvi et al. (1987) identified that some students possess a 'static' rather than a 'dynamic' understanding of chemical reactions. The opportunity to visualise the computer simulations of various reactions may indeed assist to promote this development, which in turn has resulted in a significant improvement in students' ability to balance chemical equations. Several authors have supported the use of such concrete models to help students develop an appropriate mental model of the particulate nature of matter (Gabel & Sherwood, 1980; Garnett, Tobin & Swingler, 1985).

The evidence from this study permits the following assertion (5.2) to be made.

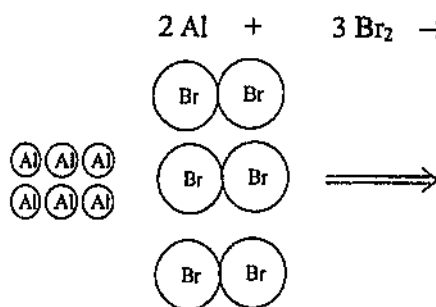
**Assertion 5.2**

*Following interaction with the IMM software there was an increase in student ability to apply stoichiometric relationships to chemical problems.*

### Student Understanding of Limiting Reagents

In Questions 10 and 11, students were presented with a symbolic representation of a chemical reaction in the form of a balanced equation and a pictorial representation of the number of particles available for reaction. In both questions, one of the two reactants was present in excess quantities. Students were asked to draw a diagram to represent the products formed and were then asked to specify the number of each chemical species present at the conclusion of the reaction.

Question 10: Draw a diagram to represent the products from the reaction of Al and  $\text{Br}_2$  particles, which is represented by the following equation.



At the end of this reaction,  
How many Al particles remain?

\_\_\_\_\_

How many  $\text{Br}_2$  particles remain?

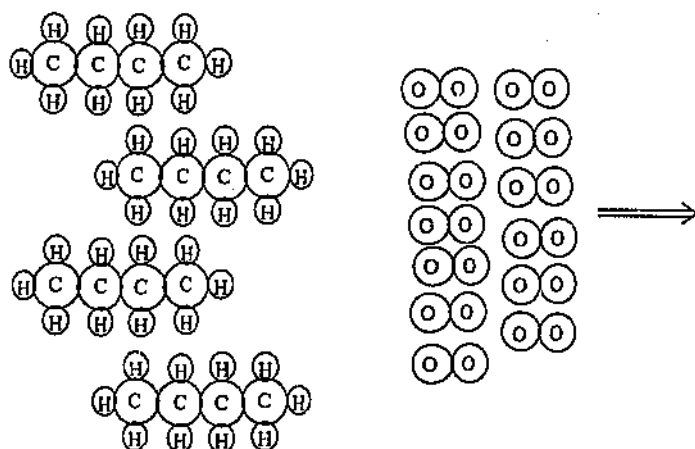
\_\_\_\_\_

How many  $\text{AlBr}_3$  particles are formed?

\_\_\_\_\_

Figure 5-3 Question 10 from pre and posttests

Question 11: Draw a diagram to represent the products formed from the reaction of  $C_4H_{10}$  and  $O_2$  particles, which is represented by the following equation.



At the end of this reaction,

How many  $C_4H_{10}$  particles remain?

\_\_\_\_\_

How many  $O_2$  particles remain?

\_\_\_\_\_

How many  $CO_2$  particles are formed?

\_\_\_\_\_

How many  $H_2O$  particles are formed?

\_\_\_\_\_

Figure 5-4 Question 11 from pre and posttests

No student was able to correctly respond to Question 10 on the pretest, however, Students 1, 2, 3, 9 and 10 did correctly draw two molecules of  $AlBr_3$ . Given additional evidence from their responses, it appears that they simply drew the number of  $AlBr_3$  particles shown in the equation. Unfortunately none of these students was able to correctly specify the number of each chemical species remaining at the conclusion of the reaction. Of these students, only Students 1 and 9 were able to specify that the bromine was the limiting reagent in the reaction. Student 2 specified numbers for Question 10 that would suggest that he misread the question and that he mistakenly specified the number of particles that took part in the reaction. Student 9 supplied answers to these question that suggested that he

determined the number of atoms taking part in the question and potentially misread the question as well.

Of the remaining students, Students 6 and 7 drew an aggregate of particles that required all of the reactants available in the pictorial representation. These students did not consider the stoichiometric ratio of chemical species in the equation when constructing their responses. Student 8 on the other hand, drew an aggregate of particles that involved the correct number of aluminium and bromine particles, but instead of separating these into two product molecules of formula  $\text{AlBr}_3$  combined them into one large molecule. This formula is consistent with the student's response to a previous question (number 6) in which he drew the representation of 2  $\text{AlBr}_3$  as one large molecule with two aluminium and six bromine atoms.

These data suggest that when students are confronted by a challenging question, that they cannot answer, they utilise related cognitive structures or schema to solve problems (Biggs & Moore, 1993). The use of such cognitive structures may not be appropriate for the question at hand, and as such the use of an inappropriate construct may signify the development of an alternative framework. For example, when struggling with reactions involving multiple quantities (meaning they have not developed strategies to deal with such problems), they utilise schema developed to deal with non-limiting reagent problems to solve the problem (even though conceptually incorrect).

On the posttest, all students except Student 7 were able to correctly draw the two product molecules for Question 10 and correctly specify the number of each chemical species remaining at the conclusion of the reaction.

Student 7 struggled again with this question and concluded that two particles of formula  $\text{Al}_3\text{Br}_3$  were produced. This response indicated that he was attempting to draw a structure or series of structures, which consumed all of the reactant particles available. This student was not able to interpret the equation and apply the stoichiometric relationships contained in it or detect that one of the reactant was present in excess quantities.



Question 11 required a similar approach to the previous task, however the particles involved in the reaction were more complex and contained more bonds and atoms. This reaction was included to provide a task with a similar logical structure as the previous, but with an increased M demand (Pascual-Leone, 1970).

Although Students 1, 3, 5, 6, 8 and 10 correctly drew eight  $\text{CO}_2$  and 10  $\text{H}_2\text{O}$  molecules on the pretest, only Student 1 detected that one of the reactants was there in excess. This suggests that the remaining students simply deduced their answer by applying the stoichiometric relationship evident in the equation, without considering the amount of each reacting quantity present. This was confirmed by interview with Student 8.

- |                     |                                                                                                                                                                                |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Interviewer:</b> | Why did you just draw 8 $\text{CO}_2$ and 10 $\text{H}_2\text{O}$ molecules?                                                                                                   |
| <b>Student 8:</b>   | ... cause in the reaction [equation] it says that for every 2 $\text{C}_4\text{H}_{10}$ 's you need 13 $\text{O}_2$ 's and get 8 $\text{CO}_2$ and 10 $\text{H}_2\text{O}$ 's. |
| <b>Interviewer:</b> | Do you have enough of the $\text{C}_4\text{H}_{10}$ and $\text{O}_2$ for the reaction?                                                                                         |
| <b>Student 8:</b>   | Must do ... otherwise how would I get 8 $\text{CO}_2$ and 10 $\text{H}_2\text{O}$ 's.                                                                                          |
| <b>Interviewer:</b> | Fine. Tell me ... what is the purpose of the diagram?                                                                                                                          |
| <b>Student 8:</b>   | Just another way of looking at the reaction.                                                                                                                                   |
| <b>Interviewer:</b> | Are they the same?                                                                                                                                                             |
| <b>Student 8:</b>   | Yeah ... if they weren't then the reaction would not occur.                                                                                                                    |

*Figure 5-5 Pretest interview B with Student 8*

When further prompted about this discrepancy, the student considered that the diagram was wrong.

- |                     |                                                                                                                       |
|---------------------|-----------------------------------------------------------------------------------------------------------------------|
| <b>Interviewer:</b> | Count the number of each particle in the diagram. Does the diagram have the same number of chemicals as the equation? |
| <b>Student 8:</b>   | [...] no it doesn't ... there are more of these [pointing to $\text{C}_4\text{H}_{10}$ molecules]                     |
| <b>Interviewer:</b> | What does that mean?                                                                                                  |
| <b>Student 8:</b>   | You made a mistake. The reaction only requires two of these ... you drew four.                                        |
| <b>Interviewer:</b> | Is there any other possible reason?                                                                                   |
| <b>Student 8:</b>   | ... don't know.                                                                                                       |

*Figure 5-6 Pretest interview C with Student 8*

Student 2 did not attempt to draw the products of the reaction, but did specify the numbers of particles for each chemical species, however, his responses suggest that he simply noted down the coefficients of the equation. This suggests that the student was either unsure of the answer or simply misread the question. When this student's incorrect response for the previous question is considered, it appears that once again, the student simply noted the coefficients of the equation and as such did not learn how to complete the task.

Student 4 showed working to indicate that he calculated the number of each reactant, and in doing so, misinterpreted the representation of the  $O_2$  molecules. The student assumed that each oxygen atom represented a molecule of  $O_2$  and as such concluded that there were 26 molecules of  $O_2$ . Support for this assertion comes from his calculation of the number of particles reacted and produced, in which he considered all reactant molecules to be used up in the reaction.

Student 9 drew eight molecules of a structure, which contained two carbon atoms and two oxygen atoms, and 10 water molecules. This response indicates that the student failed to understand the chemical structure of the molecule  $CO_2$ . This was not investigated further by interview but was consistent with earlier misconceptions regarding the formulae and composition of molecules in previous questions. The student, however, failed to check his response given the number of reacting particles in the reaction and detect that an error had been made. Therefore it can be concluded that his error was not simply one of misunderstanding the formula but also not appreciating or applying the implications of the stoichiometric ratio implicit in the chemical equation.

Student 7 drew a structure, which contained eight carbon atoms and two oxygen atoms and another, which contained 20 hydrogen atoms and one oxygen atom. In this situation the student was unable to determine the formula of the product and incorrectly applied the coefficient to the molecule. This student also did not appreciate or apply the stoichiometric ratio implicit in the chemical equation. Further to this, neither of the last two

students noted a substantial pointer to the correct formula of each individual molecule, which was stated in the question: "How many CO<sub>2</sub> particles are formed?"

On the posttest, all students were able to correctly draw the products of the reaction, Students 8 and 9, however, actually specified that two of the four reactant C<sub>4</sub>H<sub>10</sub> molecules remained unreacted. Students 7 and 10 however, still did not indicate that any of the reagents was in excess (they both considered all reactants to be totally consumed in the reaction). Again, these students showed an inability to fully appreciate the stoichiometric relationship in the balanced equation.

Student 8 did not fully appreciate that one of the reagents was not totally consumed. This student did, however, note that eight carbons (presumable from C<sub>4</sub>H<sub>10</sub>) were not converted into carbon dioxide. Nevertheless, he did not understand that the remaining reactant molecules simply did not react.

In order to determine why so many students had experienced difficulty interpreting and answering the limiting reagent questions, special attention was given to student interactions when first encountering limiting reagent problems in the IMM software. Relevant sections of dialogue between two students are provided and then discussed.

The following dialogue was recorded when the two students were completing the first limiting reagent problem section in the IMM software.

Student 8	How many hydrogens are there?
Student 9	umm ... 9 H <sub>2</sub> s.
Student 8	Why are there 9 hydrogens and only 2 nitrogens?
Student 9	Maybe we can add more nitrogens? Try it.
Student 8	Try what?
Student 9	Add more nitrogens to the box [pointing to the "before reaction box"]
Student 8	OK ....nope can't do it.
Student 9	You must be able to ... they haven't given us enough nitrogens. Give me a go ....
Student 8	See ... I told you!

Student 9	This doesn't make sense.
Student 8	Grab a $\text{NH}_3$ and put in that box [pointing to the "after reaction box"] ... good ...now grab another three.
Student 9	Why?
Student 8	If we use up one nitrogen to form ammonia, then we will be left with one and if that one reacts then all nitrogen is gone.
Student 9	OK ... so cause each nitrogen is diatomic, each one can form 2 ammonias.
Student 8	Check the answer.
Student 9	[after checking answer] How could it be wrong? We used all the nitrogen – this is stupid!
Student 8	It says that we should check the number of hydrogens ... count them there are ...1, 2, 3 ....8 hydrogens.
Student 9	If we add more hydrogen, then we will need more nitrogen.
Student 8	...[unable to decipher] ...look there are only 12 hydrogens in this box [pointing to "after reaction box"]
Student 9	So what?
Student 8	Its not balanced!
Student 9	It's not an equation – why does it have to balance?
Student 8	There are 16 hydrogens in this box and only 12 in this box ...
Student 9	Try to remove 4 then [referring to the "before reaction box"]
Student 8	It won't let me ... what about putting two hydrogens in the second box ...
Student 9	But it's a reactant, how can you make it?
Student 8	[checks answer] ... it works!
Student 9	Why ... I don't get it?
Student 8	The two hydrogens did not react ...they did nothing ...like those spectator things that Mr Grimes talks about.
Student 9	So just because a thing is a reactant, they don't all have to react? I thought that it was called a reactant because they all reacted.
Student 8	No ... I think it means that they can react ... its just that sometimes you have too much of one and too little of another.
Student 9	Why is the hydrogen allowed to be in the product box ... its not a product, it's a reactant?
Student 8	I get it! Its not a product box ... it simply shows what is left after everything [the reaction] has finished.

Figure 5-7 Interaction sequence A within Dyad 5

This extended dialogue demonstrates that both students had a prior conception that the left hand side of the equation represented the reactant and that the right represented the products. This was also reinforced by the equation displayed in the IMM software and by previous classroom experience. This resulted in the students developing an understanding

of chemical reactions in which there was a total separation of reactants and products. This understanding of chemical reactions also included a rationalisation that all reactants were 'used up'. These representations were in direct conflict with the work exercises presented by the IMM software in which one quantity was limiting.

### **Discussion and Assertions**

These data indicate that prior to using the IMM software none of the students understood the concept of limiting reagents. This is not surprising as none of these students had encountered this concept in previous classroom instruction, although all would have experienced such events in their laboratory course, such as the burning of magnesium or the addition of a small amount of acid to excess calcium carbonate. That is, although students had experienced the practical realities and consequences of limiting reagents in their laboratory work and indeed, real life experiences, they did not conceptualise those experiences in terms of limiting reagents. This may be another example of the separation of the two worlds of knowledge (ie. scientific and commonsense real-world knowledge) as described by Solomon (1993).

Further research into the reasons why so many students experienced difficulty interpreting and answering limiting reagent question, were conducted by examining the nature of student interactions when first encountering limiting reagent problems in the IMM software. The dialogue presented (in the previous section) indicates that the cognitive conflict affected the two students quite differently, with one becoming quite disgruntled and frustrated and the other considering it as a challenge. This reaction was termed by Gorsky and Finegold (1994) as disequilibrium, which is characterised by both rational and emotional responses, which can result in a range of behavioural responses. Disequilibrium is considered by these researchers to be a necessary precursor to conceptual change.

In this dialogue, both students displayed behaviours consistent with disequilibrium when their construction of chemical reactions was challenged. Initially, the relative number of reactant particles confused them, then after determining the number of ammonia molecules produced, were frustrated that their answer was incorrect. When one student had

concluded that there were two molecules of hydrogen gas too many in the left hand box, they tried to remove them. This action is consistent with their previous experience of the number of reacting quantities available for reaction.

The students eventually came to an appreciation of the concept of limiting reagents, but only through the perseverance of Student 8. In subsequent examples these students were able to obtain the correct answer however, not without prompting from the IMM software. This concept appeared to be a quite an obstacle for these students and represented a 'quantum leap' to their construction, which took some practice and experience to achieve success. This concept did not appear a simple addition to their knowledge of chemical reactions, but rather a reconceptualisation or an accommodation of their understanding, which required cognitive conflict and repeated practice to generate understanding.

The evidence from this study permits the following assertion (5.3) to be made.

*Assertion 5.3*

*Learning about limiting reagents is not a simple addition to existing schema. Rather, the data presented here suggests that it requires some re-organisation of existing structures.*

This reconceptualisation was hindered by their understanding of the term 'product'. This was confirmed by interview with Students 8 and 9, who initially considered it to be "chemicals found at the end of a reaction". After interaction with the IMM software Student 9 defined the term as "things that are on the right hand side of the arrow in a chemical reaction" and Student 8 as "any chemical that is made during a chemical reaction ... it does not include left over starting materials". This indicates that Student 8 had, as a result of cognitive conflict, redefined the term product and that Student 9 although having completed the relevant exercises with Student 8 had not come to terms with the concept of limiting reagents. This also illustrated that the IMM software had a limited capacity to alter the alternative concepts that students had generated of the term 'product'.

The influence that definitions have on the organisation and conceptualisation of new ideas is highlighted when a comparison is made between students and an experienced scientist, who defined the term product as "a chemical species that is produced in a chemical reaction as a result of a series of bond breaking and/or bond forming processes" (Ellison, M.J., personal communication, May, 17, 2000). The definition understood by the students encapsulated their knowledge and prevented further construction or additions to existing schema. In order for the student to develop an appreciation for the limiting reagent concept, the student had to experience a cognitive conflict with the evidence presented and his existing schema, which resulted in his construction of this term being reviewed and updated. Only after such conflict had occurred could the student form the foundation to develop this new concept.

The evidence from this study permits the following assertion (5.4, 5.5) to be made.

*Assertion 5.4*

*Students' ability to answer limiting reagent questions correctly is influenced by their concept of a 'product'.*

*Assertion 5.5*

*Interaction with the IMM software had limited impact in altering some students' alternative concept of the term 'product'.*

The data presented support the findings of Ben-Zvi et al. (1987) and Nurrenberg and Pickering (1987) who identified and described students' lack of understanding of chemical change to be a result of their inability or willingness to visualise chemical equations at the particulate level and then make the connection between this and the symbolic representation of the balanced equation. The data also supports the findings of previous alternative conceptions research, which has illustrated, according to Garnett et al., (1995) that conceptions developed by students are often different from those expected and that these conceptions can influence subsequent learning. These authors also commented on the

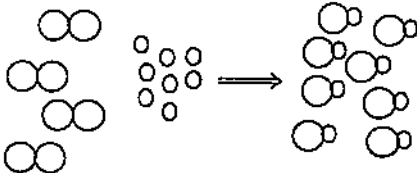
works of Novak (1988) who stated that such alternative conceptions may be highly resistant to change.

### Writing Balanced Chemical Equations from Pictorial Representations

This question was the most complex and required students to identify chemical species in a pictorially represented equation, identify the number of different reactants and products and then use the given symbols and pictorial representation to construct an equation to represent the reaction.

Question 12: Look at the reactions, which are represented by the following diagrams and answer the attached questions.

a.



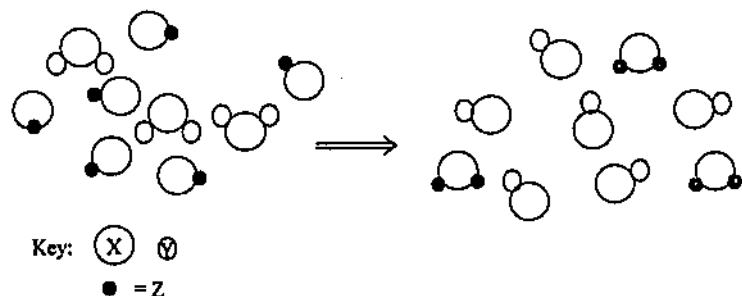
Key:  $\bigcirc_X$   $\bigcirc_O$

- How many different types of reactant particles are in this reaction?
- How many different types product particles are in this reaction?
- Write a reaction that represents this reaction using appropriate symbols.

Figure 5-8 Question 12a from pre and posttests



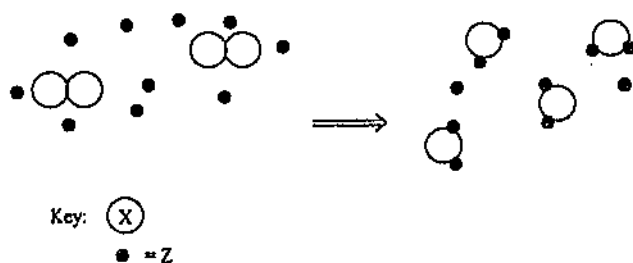
b.



- (i) How many different types of reactant particles are in this reaction?
- (ii) How many different types product particles are in this reaction?
- (iii) Write a reaction that represents this reaction using appropriate symbols.

Figure 5-9 Question 12b from pre and posttests

c.



- (i) How many different types of reactant particles are in this reaction?
- (ii) How many different types product particles are in this reaction?
- (iii) Which chemical is not completely used up?
- (iv) How many of these unreacted particles remain?
- (iv) Write a reaction that represents this reaction using appropriate symbols.

Figure 5-10 Question 12c from pre and posttests

In part (a) students were given a reaction involving one monatomic reactant and one diatomic reactant, present in stoichiometrically correct amounts to produce a single product. In this problem there was no limiting reagent and both reactants were completely used up in the reaction.

Students 2, 4, 5, 6, 7 and 8 were able to correctly deduce that there were only two different types of reactant particles and one type of product particle. In contrast, Student 1 stated that there were eight different types of reactant particles and two types of products. The latter of which could be rationalised on the basis that he considered each different atom type (X and Y) to be a different product even though they were combined to form a single product in the reaction. Student 3 stated that there were 16 different reactant types, which suggests that he simply counted up the total number of atoms in the reacting particles, yet selected the correct response for the number of products.

In their attempts to write a balanced equation to represent the reaction, Students 2, 3, 4, 5, 6 and 9 were able to correctly assign an appropriate formula to each chemical species and formulate an equation, however, in their efforts to balance the equation they simply added up the number of each particle in the pictorial representation. These students did not reduce the number of reacting particles to the most basic whole number ratio, as required by reaction stoichiometry. Student 1 did not use the symbols provided for each of the species, but instead substituted them for hydrogen and chlorine atoms (both of which he considered to be monatomic). This student's equation did indeed balance, but did not represent the most basic ratio of chemical species and was founded on incorrect formulations. Student 7 provided an idiosyncratic answer, which does not fit any of the standard misconceptions. Students 8 and 10 were the only ones that managed to respond correctly to all questions asked. They were able to derive correct formulae for the chemical species, determine the stoichiometric relationships between them, and write an equation for the reaction.

In the posttest, all students were able to write appropriate formulae for the chemical species in the equation and write a balanced equation, however, only Students 8 and 10 were able to correctly determine the correct stoichiometric ratio.

In part (b) students were given a reaction between two reactants to produce a single product. On the pretest, Students 1 and 7 did not complete the question. Students 2, 4, 5 and 10 answered all questions correctly and manage to write a balanced chemical equation however, it was not reduced to the most basic stoichiometric ratio as was required. Student 3 wrote a similar equation however, considered all reactant particles as different types, giving a response of 21 particles as opposed to only two. Student 9 considered the different elements involved in the reactant molecules as different reactant particles and gave an answer of three instead of two. This student also incorrectly wrote the formula of one of the product molecules as  $XY_3$  as opposed to there being 3 XY molecules. This indicates an error in the interpretation of the meaning of the subscript. Only Student 8 correctly answered all questions and wrote a well balanced, stoichiometrically correct equation.

On the posttest, Students 1, 2, 3, 4, 5, 6, 7 and 9 correctly answered all questions and managed to write the correct formula for all chemical species, write a balanced equation, however, the coefficients were not reduced to the most basic stoichiometric ratios. Only completely correct and perfectly balanced equations were written by Students 8 and 10.

In part (c) students were once again given a reaction between two reactant particles, one of which was in excess to produce a single product. This was one of the most difficult tasks since one of the reactants was present in excess. On the pretest, all students except 1 and 3 could identify that only two types of reactant particles were present. Further, all students stated that two types of product particles were produced, yet all were able to determine that one of the reactants was in excess. This indicates that students have a different perception and understanding of the term 'product' compared to a scientist. This was previously illustrated and discussed in the analysis of Questions 10 and 11 in an earlier section of this Chapter.

When asked to write an equation to represent the reaction only Student 7 could not correctly write the required formulae for each of the chemical species. From the remaining responses Students 2, 3, 4, 6 wrote balanced equations but did not remove the excess reagent from the equation, which did not take part in the reaction. Students 1 and 10 removed the excess from the right hand side of the equation, indicating that it was not a product, but did not remove it from the reactant side resulting in a non-balanced equation. Only Student 5 removed the excess reagent from both the reactant and the product side of the equation however, he failed to reduce the coefficients to the correct stoichiometry.

On the posttest, Students 2, 3, 4, 8 and 10 were able to correctly answer all questions, thus being able to identify the number of different types of reactant and particles, identify chemical species in excess and then write a balanced chemical equation that utilises correct symbols and formula structure and represents the stoichiometry of the reaction under investigation. Of the remaining, Students 6, 7 and 9 were able to correctly identify the number of different types of reactant and product particles, as well as the number of particles and type of particles in excess. These students however, in the formulation of a representative chemical equation, included the excess reactant in the equation. They also failed to reduce the stoichiometry to its most basic ratio. Student 5 answered the leading question correctly, but was unable to correctly balance the chemical equation. This student did not include the excess reactant, but also did not reduce the equation to its most basic stoichiometry. Student 1 on the other hand, correctly identified the number of different types of reactants, but incorrectly considered the excess reactant as a product. This student was unable to write a well-balanced equation and appears to have listed coefficients based upon the number of particles illustrated in the equation and as such did not consider reaction stoichiometry.

### **Discussion and Assertions**

These data indicate that students are able to identify and write formulae for reactants and products, but initially considered excess reagents to be products of the reaction. Further, they considered the coefficients used in equations to represent the total

number of particles involved in the reaction as opposed to the relative ratios of those reacting or produced in the reaction.

Further many students initially considered that subscripts in the formulae of chemicals could be used in balancing equations and do not represent atomic or molecular groupings. This misconception, made by many students, is illustrated by assertion 5.6. The data presented here also supports the findings of Ben-Zvi et al. (1987) and Nurrenberg and Pickering (1987) who identified and described students' lack of understanding of chemical change to be a result of their inability or willingness to visualise chemical equations at the particulate level and then make the connection between this and the symbolic representation of the balanced equation.

The evidence from this study permits the following assertions (5.6, 5.7) to be made.

***Assertion 5.6***

*A consistent misconception by students is that subscripts in formulae are numbers used in balancing equations and do not represent atomic groupings.*

***Assertion 5.7***

*Students are able to identify and write formulae for reactants and products, but consider that the coefficients applied to these particles is the total number reacting as opposed to the relative ratios of those reacting or produced in the reaction.*

As already illustrated in this Chapter, many researchers have documented the difficulties experienced by students in balancing chemical equations. These researchers have invariably related these difficulties to the inadequate student models of the particulate nature of matter. Garnett et al., (1995) have proposed that "modern multimedia technology

offers exiting possibilities to provide students with opportunities to observe through simulation the particulate/ submicroscopic nature of matter in its various states and forms and the interactions underlying physical and chemical change" (p. 91). Support for this statement has come from many sources, including the work of Reiber (1990), in which it was argued that such technologies can provide a suitable explanation for dynamic processes and heighten the impact of a presentation. Further, Orr, Golas and Yao (1994) noted that animations can offer the ability to highlight key information, heighten student interest and facilitate recall.

The use of such animations to provide a concrete model of the particulate nature of matter and facilitate learning can be understood in terms of the dual-coding theory (Paivio, 1979), which is based on the assumption that human cognition is based upon a verbal and a visual information processing system. This theory assumes that the coding of information in both of these forms (verbal and visual) has an additive effect, which can enhance learning. Animations, such as those utilised in the IMM software *Balancing and Interpreting Chemical Equations* provide the ability for information to be coded in both forms. Evidence from collected data suggest that students developed a more detailed and accurate representation of the particulate nature of matter following interaction with the IMM software.

The evidence from this study permits the following assertion (5.8, 5.9) to be made.

***Assertion 5.8***

***Students developed a more detailed and accurate representation of the particulate nature of matter following interaction with the IMM software.***

***Assertion 5.9***

***Students' ability to write balanced equations from pictorial representations improved following interaction with the IMM software.***

## Chapter Summary

The assertions developed throughout this chapter are summarised below:

- 5.1 *The majority of students were able to read and interpret the basic stoichiometry of an equation, but were unable to apply these relationships to multiple quantities.*
- 5.2 *Following interaction with the IMM software there was an increase in student ability to apply stoichiometric relationships to chemical problems.*
- 5.3 *Learning about limiting reagents is not a simple addition to existing schema. Rather, the data presented here suggests that it requires some re-organisation of existing structures.*
- 5.4 *Students' ability to answer limiting reagent questions correctly is influenced by their concept of a 'product'.*
- 5.5 *Interaction with the IMM software had limited impact in altering some students' alternative concept of the term 'product'.*
- 5.6 *A consistent misconception by students is that subscripts in formulae are numbers used in balancing equations and do not represent atomic groupings.*
- 5.7 *Students are able to identify and write formulae for reactants and products, but consider that the coefficients applied to these particles is the total number reacting as opposed to the relative ratios of those reacting or produced in the reaction.*
- 5.8 *Students developed a more detailed and accurate representation of the particulate nature of matter following interaction with the IMM software.*

**5.9**    *Students' ability to write balanced equations from pictorial representations improved following interaction with the IMM software.*



## **CHAPTER 6**

### **RESULTS AND DISCUSSION**

#### **STUDENT'S INTERACTION WITH THE IMM SOFTWARE**

##### **Introduction**

This Chapter presents and interprets the data related to the students' interactions with the IMM software, and in particular, the order in which various components of the IMM software were accessed, the repetition of such access and the length of interaction with the software. These data were obtained by analysing video capture of computer screens and were confirmed by the Researcher's observations and notes. These data are discussed and then several assertions are made relating to this theme. This Chapter also considers which student of the dyad had control over the interaction with the software and the total instructional time that students utilised the software. Researcher observations and video data are discussed and assertions made regarding this aspect of student interactions with the program.

##### **Learner Control and the Sequence of Instructional Paths**

Learner control refers to the freedom that learners possess when interacting with instructional materials. This freedom permit learners to make a variety of decisions about the instructional paths that will be utilised throughout the IMM software, the scope and extent of inquiry into different modules and the subsequent content that will be examined. Such learner control was considered by Steinberg (1989) to individualise the instructional process and make it more motivating. While this has been considered to be an advantage of interactive computer systems and the World Wide Web (WWW) as a learning environment, learners have often been found to lack the understanding and cognitive skills required to take full advantage of these learning environments (Heller, 1990; Trumball, Gay & Mazur,

1992). In addition, students often lack sufficient knowledge of the particular subject matter of an IMM software to select the most appropriate instructional paths through the software, in order to enhance and maximise learning opportunities.

In the IMM software *Balancing and Interpreting Chemical Equations* students are able to select a chemical reaction for study and then analyse it macroscopically (Demonstration), at the particulate level (Simulation) or at the symbolic level (Equation). The software includes three levels of representation to enhance students' understanding of the reaction process, which should help them to successfully balance and interpret chemical equations.

Students worked in pairs on the IMM software. The order in which the various levels of representation were utilised by each dyad was determined and is shown in Table 6-1. This Table indicates the percentage of occasions that each level of representation was accessed first, second or third in the learning sequence.

Table 6-1

*Percentage of occasions that each level of representation was accessed first, second or third in the learning sequence*

Dyad		Demonstration			Simulation			Equation		
		First	Second	Third	First	Second	Third	First	Second	Third
Scaffolded Dyad	1	100	0	0	0	100	0	0	0	100
	2	100	0	0	0	100	0	0	0	100
	3	100	0	0	0	100	0	0	0	100
Non-scaffolded Dyad	4 <sup>a</sup>	38	62	0	0	25	25	63	12	25
	5 <sup>a</sup>	72	0	0	28	72	0	0	28	72
	6 <sup>a</sup>	100	0	0	0	58	0	0	0	58

Note: <sup>a</sup> Dyads 4, 5 and 6 did not access every level of representation for each reaction

### Dyads 1, 2 and 3

These data indicate that Dyads 1, 2 and 3 selected the instructional path incorporating the Demonstration prior to the Simulation and finally the Equation module on all occasions. This is not surprising, given that this instructional path was recommended by the scaffolded instructions supplied to these dyads. There was a greater variety in the selected instructional paths selected by the non-scaffolded dyads 4, 5 and 6. This difference in sequencing of instructional paths between scaffolded and non-scaffolded dyads prompted further investigation through student interview, an excerpt of which is shown in the following passage.

<b>Interviewer:</b>	While you were using the program I noticed that you always accessed the Demonstration module, followed by the Simulation module and then the Equation module. Why?
<b>Student 1:</b>	I just followed the worksheet that you gave us.
<b>Interviewer:</b>	Why do you think that it asked you to do this in that order?
<b>Student 1:</b>	I am not really sure.
<b>Interviewer:</b>	Is there any advantage to completing the task in that order?
<b>Student 1:</b>	Well ... by looking at the demonstration we had to list the names of the chemicals and the lady [audio voice used in program] told us what they were and we got their colours [the chemicals], then when we saw the simulation we could find out the formulas of the chemicals and we could see the number of each chemical reacting.
<b>Interviewer:</b>	How can this information help you balance the equation?
<b>Student 1:</b>	The colours don't ... its just additional info but by looking at the simulation you can get the number of elements in the molecule ummm ... its formula and then can get the number of things reacting. That's what balancing is. The order made us go from big picture stuff down to atoms and the equation.

*Figure 6-1 Interview A with Student 1*

This interview excerpt illustrates that the student not only followed the prescribed sequence of tasks in the scaffolded guides, but was also able to identify the three levels of representation utilised in the IMM program. This student also displayed some awareness of how a consideration of the various levels of representation could assist in the process of balancing a chemical equation. Such metacognition could assist the student to balance chemical equations and other chemical problems in the future by allowing him to consider the problem from an alternative level of representation.

#### **Dyad 4**

The modules selected first were the Demonstration (38%) and the Equation (63%) modules. The modules selected second in the various exercises were Demonstration (62%), Simulation (25%) and Equation (12%). The modules selected third were the Simulation and Equation modules (25% each). These results indicate that this dyad utilised the Demonstration and Equation modules for every exercise, however, only viewed the

Simulation module in 50% of all exercises attempted. Further, in 63% of all exercises, this dyad attempted the Equation module prior to accessing the other modules. This is surprising since both the Demonstration and Simulation modules provide information to assist the learner write and balance equations in the Equation module. This suggests that this dyad did not consider the Demonstration and Simulation modules to be beneficial in helping to balance the equation. This was illustrated by the following excerpt from an interview conducted with one member of this dyad.

- Interviewer:** While you were using the program I noticed that on many occasions you attempted to balance the equation without looking at the Demonstration or the Simulation modules. Why?
- Student 12:** I thought that we had to complete all the equations?
- Interviewer:** Well ...yes you did, however, why did you not watch the Demonstration or the Simulation?
- Student 12:** Because we wanted to do as many questions as we could and didn't want to waste any time. We watched some of the demos and simulations because they looked good.
- Interviewer:** Would those other modules ...the Demonstrations or Simulations have assisted you to balance the equations?
- Student 12:** No. Balancing equations is just problem solving.
- Interviewer:** Why do you think that the authors of the program included these other parts?
- Student 12:** Probably because they want to teach us about the reactions properly.
- Interviewer:** How do the other modules do that?
- Student 12:** The demos show us how to do the reaction and the colours of things ... and the simulation shows us the actual reaction.
- Interviewer:** Why do think that showing you the reaction is important?
- Student 12:** We can't see the reaction ... the particles are too small ... so we need computer graphics to visualise what is happening.
- Interviewer:** Does the demonstration or simulations help you balance the equation?
- Student 12:** No. They teach us other things about the reaction.

*Figure 6-2 Interview A with Student 12*

### Dyad 5

The modules selected first were the Demonstration (72%) and the Simulation (28%) modules. The modules selected second in the various exercises were Simulation (72%) and Equation (28%). The module selected last was the Equation module (72%). These results indicate that this dyad viewed the Demonstration module first in 72% of all exercises and did not view it at all in 28% of exercises. Further, the Equation module was accessed after either the Demonstration or Simulation modules. This suggests that these students utilised the Demonstration and Simulation modules on some occasions prior to the Equation module and on other occasions only accessed the Simulation module to assist learning prior to the Equation module. The following interview excerpt illustrates that these students did not consider the demonstration module to provide any assistance or information relevant to balancing chemical equations and were only there to show the reaction. An analysis of the contained demonstrations illustrates that information is provided about the state, formulae and various physical properties, which can be of assistance in the process of balancing a chemical equation.

- |                     |                                                                                                                                                            |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Interviewer:</b> | While you were using the program I noticed that on some occasions you attempted to balance the equation without looking at the Demonstration modules. Why? |
| <b>Student 9:</b>   | Did we do it wrong?                                                                                                                                        |
| <b>Interviewer:</b> | Definitely not! You were allowed to do as little or as much as you wanted to. I was just wondering why you didn't use the Demonstration module sometimes.  |
| <b>Student 9:</b>   | Some of the demos were really cool and looked great. We watched some because of that and on others we decided just to balance the equation.                |
| <b>Interviewer:</b> | Does the Demonstration give you any help in balancing equations?                                                                                           |
| <b>Student 9:</b>   | I don't think so ... I thought that it was there for us to watch it.                                                                                       |
| <b>Interviewer:</b> | What about the simulations. Were they helpful in learning how to balance an equation?                                                                      |
| <b>Student 9:</b>   | They help us see what a reaction looks like.                                                                                                               |
| <b>Interviewer:</b> | But did they help you balance the equation?                                                                                                                |
| <b>Student 9:</b>   | No. We still had to add up all of the atoms on both sides of the arrow.                                                                                    |

*Figure 6-3 Interview A with Student 9*

### Dyad 6

The module selected first in all exercises was the Demonstration module (100%). This was followed next by the Simulation module (58%) and then by the Equation module (58%). On 58% of all exercises, this Dyad selected the Demonstration, followed by the Simulation and finally the Equation module. On the remaining 42% of all exercises the Dyad only accessed the Demonstration module. In these 42% of exercises, the Dyad did not complete the required task of attempting to write the equation for the represented chemical reaction. Supporting data from the Researcher's notes indicate that these students were 'off task' for much of this time, preferring to look at the "cool reactions on video" as opposed to studying the reaction at the particulate and symbolic levels provided.

Within each exercise, dyads were able to view a particular module more than once if required, in order to understand and interpret the information provided. The frequencies with which particular modules were accessed were recorded and are summarised in Table 6-2.

Analysis of these results indicates that Dyads 1, 2 and 3 made use of each of the modules in every exercise attempted. These students used both Demonstration and Simulation modules several times, and at least twice on all occasions. This is not surprising, given the nature of the directions and questions provided to them on the scaffolded worksheets, which varied in the degree of scaffolding provided, as previously described. These worksheets required students to view a Demonstration with a particular purpose in mind and then replay the Demonstration, in order to observe and focus on a different feature of the reaction under study. This approach was replicated with the scaffolded worksheets for the Simulation but not with the Equation module.

Table 6-2

*The frequency with which various modules were accessed for each exercise attempted.*

Dyad	Modules accessed	Exercises attempted											Average repetitions for dyad
		1	2	3	4	5	6	7	8	9	10	11	
1	Demonstration	3	2	3	3	4	4						3.2
	Simulation	9	6	3	6	3	3						5
	Equation	1	1	1	1	1	1						1
2	Demonstration	3	3	3	3	4	4						3.3
	Simulation	9	7	3	6	4	3						5.3
	Equation	1	1	1	1	1	1						1
3	Demonstration	4	4	5	4								4.25
	Simulation	13	5	4	7								7.25
	Equation	1	1	1	1								1
4	Demonstration	2	3	2	2	1	2	1	2				1.8
	Simulation	2	0	0	1	0	1	2	0				0.75
	Equation	1	1	1	1	1	1	1	1				1
5	Demonstration	2	1	1	1	1	1						1.2
	Simulation	2	1	2	1	1	1						1.3
	Equation	1	1	1	1	1	1						1
6	Demonstration	3	3	1	1	3	1	1	1	1	1	1	1.5
	Simulation	1	0	0	0	0	0	1	1	1	1	1	0.55
	Equation	1	0	0	0	0	0	1	1	1	1	1	0.55

Further analysis of the results from Dyads 1, 2 and 3 indicate that the number of module repetitions per exercise decreased with student experience. This statistic is consistent with student use of the tiered scaffolded worksheets. The use of these varying levels of scaffolded worksheets by Dyads 1, 2 and 3 is shown in Table 6-3. This Table illustrates that both Dyads 1 and 2 made an effort to move from the most scaffolded worksheet (Level 1) to the least (Level 3), whereas Dyad 3 only progressed from worksheet Level 1 to Level 2. The Table also illustrates that these dyads only completed four exercises in comparison to Dyads 1 and 2, who managed to complete six exercises each. This slower work rate (compared to Dyads 1 and 2) may be the result of one or more of the following



factors: decreased confidence, ability or the use of the more structured worksheets, which required greater repetition and interaction with the IMM software.

**Table 6-3**

*The level of scaffolded worksheets selected by each dyad per exercise.*

	<b>Level of scaffolded worksheet used</b>					
<b>Dyad</b>	<b>Ex 1</b>	<b>Ex 2</b>	<b>Ex 3</b>	<b>Ex 4</b>	<b>Ex 5</b>	<b>Ex 6</b>
<b>1</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>3</b>
<b>2</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>3</b>
<b>3</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>2</b>		

Dyads 4, 5 and 6 showed significantly less repetition of the modules, with the majority of modules being accessed less than twice per exercise. In fact, Dyad 6 only accessed the Demonstration module for five of the 11 exercises attempted. These students often appeared to be viewing the Demonstration or Simulation modules for 'entertainment value' as opposed to examining it with directed purpose. These students did not appear as focussed as other dyads and spent a great deal of time 'off-task', discussing issues not connected to the chemistry under study.

When the number of module repetitions are compared, as shown in Table 6-2, it can be seen that Dyads 1, 2 and 3 accessed the Demonstration and Simulation modules far more frequently than Dyads 4, 5 and 6. These figures indicate that the scaffolded dyads used the various modules more frequently than the non-scaffolded dyads. Although this is not surprising, given the scaffolding provided, it is interesting to note that these dyads accessed the Demonstration and Simulation modules with greater frequency than that prescribed by the scaffolded worksheet that they used on each exercise. These data are summarised in Table 6-4. This suggests that these students found these modules useful in helping them understand and balance the chemical equations. Students were not required to repeat the Equation module and as such, student repetition of this module is not discussed further. The

data also show that the scaffolded dyads utilised the Simulation module more frequently than the Demonstration modules. This reflects the number of repetitions prescribed by the scaffolded worksheets but also of the personal learning habits of these students who gained much from their interaction with each other and the simulations.

Table 6-4

*The number of times (N) each module was accessed by each of the scaffolded dyads compared to the number prescribed by the scaffolded worksheet used in the exercise (P).*

Dyad		Number of repetitions per exercise											
		Exercise 1		Exercise 2		Exercise 3		Exercise 4		Exercise 5		Exercise 6	
		N	P	N	P	N	P	N	P	N	P	N	P
1	Demonstration	3	2	2	2	3	1	3	2	4	1	4	1
	Simulation	9	5	6	4	3	2	6	4	3	2	3	2
2	Demonstration	3	2	3	2	3	1	3	2	4	1	4	1
	Simulation	9	5	7	4	3	2	6	4	4	2	3	2
3	Demonstration	4	2	4	2	5	2	4	2				
	Simulation	13	5	5	4	4	4	7	4				

## Discussion and Assertions

The ability to move from the macroscopic to the particulate and then to the symbolic can represent a significant challenge for learners (Johnstone, 1991). This was supported by Ben-Zvi et al. (1988, p. 89) when they indicated that "much has been said about the abstract nature of chemical concepts and the inability of students who have not reached the 'formal' stage (as defined by Piaget) to cope with these concepts." These researchers believed that the "root of many difficulties that beginning chemistry students have, appear to be deficient understanding of the very basic atomic model and how it is used to explain macroscopic properties and the laws of chemistry" (p. 89).

In fact, an analysis of many chemistry texts and teachers' lesson plans indicate that students are required to move very quickly between the macroscopic, particulate and

symbolic levels of representation. This appears to represent significant difficulties for many students and is often not explicit enough in teachers' explanations and discussions. This view was supported by the work of Johnstone (1991) when he stated, "so much of teaching takes place *within* the triangle where the three levels [macroscopic, particulate and symbolic] interact in varying proportions and the teacher may be unaware of the demands made on the pupil." (p. 78)

The IMM program *Balancing and Interpreting Chemical Reactions* provides opportunities to consider reactions under study from a macroscopic, particulate or symbolic perspective and thus has the potential to enhance students' learning, provided such materials are accessed in an appropriate order.

The data indicate that students in the scaffolded dyads utilised all three levels of representation available, and in the order specified by the scaffolded instructions for all exercises attempted. The data also suggest that some students in the scaffolded dyads developed an appreciation and understanding of the value of these levels of representation at a metacognitive level. The repeated use of the various modules suggests that they were utilising the information provided, to develop a better understanding of the chemical equations, and that they found such information useful in completing the exercises of balancing equations. This further suggests that for these learners, their metacognition was enhanced by using the scaffolded worksheets. The use of the term metacognition, is based on Gunstone's (1994) view, in which he described it in the following terms:

"....learners are appropriately metacognitive if they consciously undertake an informed and self-directed approach to recognising, evaluating and deciding whether to reconstruct their existing ideas and beliefs. By informed, I mean recognise and evaluate, with an understanding of learning goals, of relevant uses of the knowledge/ skills/ strategies/ structures to be learned, of the purposes of particular cognitive strategies appropriate to achieving these goals, of the processes of learning itself ...." (p. 133).

The value of repeated viewing of the modules, in particular the simulation module, can be appreciated from the consideration of the vast amount of information contained in

these screens. This necessitates that in order for students to attend to the salient features of the module at the appropriate time, they need to be directed to these features in a particular sequence and then be given multiple opportunities to make sense of the sensory information. The use of scaffolding in these situations serves to focus student attention on particular features at relevant times and prevents the overloading of working memory, permitting students to have a better opportunity to attend to the appropriate sensory information.

The assertion that students in the scaffolded dyads developed an appreciation of the usefulness of the various levels of representation at a metacognitive level was drawn from the fact that each scaffolded dyad utilised the various modules more frequently than prescribed by the scaffolded worksheets.

The evidence from this study permits the following assertions (6.1 - 6.3) to be made.

***Assertion 6.1***

*Students in the scaffolded dyads utilised instructional paths for all exercises attempted from a macroscopic, particulate to a symbolic level of analysis.*

***Assertion 6.2***

*Some students in the scaffolded dyads developed an appreciation, at a metacognitive level of how the various levels of representation contributed to their understanding of the chemical reactions and to their ability to balance the chemical equation.*

### ***Assertion 6.3***

***On average, students in the scaffolded dyads viewed the Demonstration and Simulation modules for the various reactions more frequently than those in the non-scaffolded dyads.***

Such repetition of the modules did however decrease in the scaffolded dyads with experience and success, and as they selected worksheets with lower levels of scaffolding. This movement from higher to lower scaffolding and support appears to be a function of confidence, success and experience. This movement from higher to lower levels of scaffolding is defined within the bounds of the Cognitive Apprenticeship Model of Instruction as fading (Collins et al., 1989; Hennessy, 1993; Roth, 1995). These authors indicate that the level of scaffolding can be reduced as students gain in competence.

The evidence from this study permits the following assertion (6.4) to be made.

### ***Assertion 6.4***

***Students in the scaffolded dyads moved from worksheets with higher levels of scaffolding to those with lower levels of scaffolding as they gained experience, success and confidence.***

In comparison, students in the non-scaffolded dyads accessed the various levels of representation less often and in an irregular order. The students' approach was unsystematic and did not support the conceptualisation of the reaction from the macroscopic to particulate and finally to the symbolic form. These students did not appear to consider the Demonstration and Simulation levels of representation helpful in the process of learning how to balance chemical equations. These students considered that the Demonstration and Simulation modules provide additional information about the reaction, rather than helping them to understand and balance the chemical equations.

Although it is expected that the scaffolded dyads would access the Demonstration and Simulation modules more frequently than the non-scaffolded dyads, the limited use of the modules by non-scaffolded dyads was surprising. This suggests that without such guides students do not see the need for, or importance of repeated use of these instructional modules.

The evidence from this study permits the following assertions (6.5 - 6.7) to be made.

*Assertion 6.5*

*Students in the non-scaffolded dyads utilised instructional paths in an irregular manner that did not support the conceptualisation of the reaction from the macroscopic to particulate and finally to the symbolic form.*

*Assertion 6.6*

*Some non-scaffolded student dyads did not utilise the Demonstration and/or Simulation modules for all of the exercises attempted.*

*Assertion 6.7*

*Scaffolding worksheets are needed to guide students through an appropriate learning pathway involving all of the modules.*

## Learner Control

Research has suggested that individual learning can at times result in many gains, but has the potential to render a learner inactive (Cooper, 1995). Previous studies have suggested that collaborative learning environments have the potential to create more engaging and dynamic educational settings and that such settings produce significant educational advantages over individual learning (Del Marie Ryysavy & Sales, 1991; Slavin, 1992). Collaborative and cooperative IMM learning environments have important practical applications in many schools, given that few schools are able to provide students with access to interactive software on an individual basis.

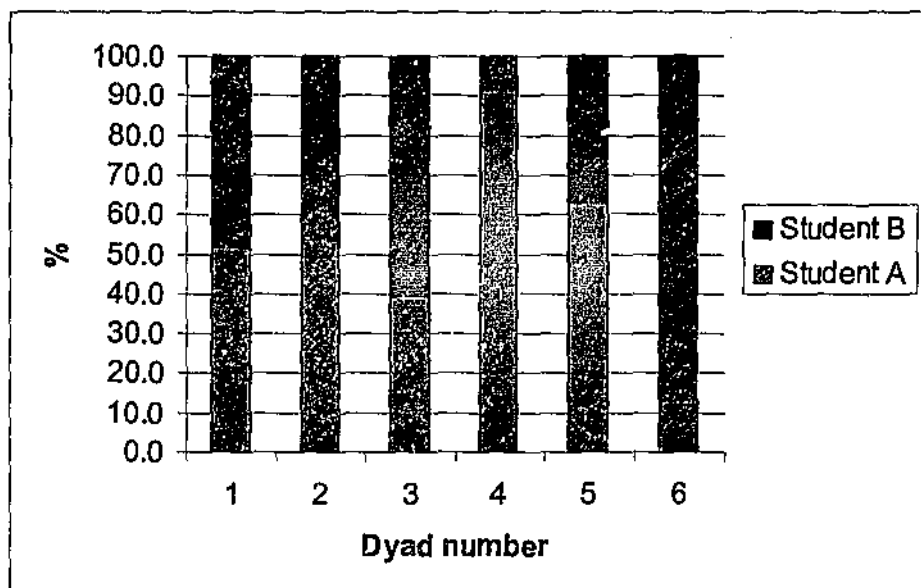
An important aspect of students working with IMM software in pairs, is which student has the ownership of instructional decisions and which one has learner control. The student who has ownership of instructional decisions is that person who makes the various decisions that influence the instructional pathway accessed. The student with learner control, is defined as the person who inputs data into the computer. In this study, it was established that learner control of the mouse was not always accompanied by ownership of instructional decisions. This was typified by the following discussion between Students 2 and 3, in which Student 3 had learner control.

<b>Student 2:</b>	Did you get that?
<b>Student 3:</b>	Yeah.
<b>Student 2:</b>	[no discussion moves mouse and selects the Equation module.]
<b>Student 3:</b>	What are you doing? Put it back.
<b>Student 2:</b>	But we've done it.
<b>Student 3:</b>	I want to see it again.
<b>Student 2:</b>	[no discussion moves mouse over to repeat Simulation]

*Figure 6-4 Interaction sequence A within Dyad 2*

Observations made by the Researcher indicate that in the majority of situations, the ownership of instructional control was retained by the student with learner control. This suggests that such control is a significant factor in the cooperative learning environment. When such control is compared between scaffolded and non-scaffolded dyads, it can be

seen that there appears to be a more even distribution of learner control in the scaffolded dyads than in the non-scaffolded dyads. This is illustrated in Figure 6-3, in which the percentage of time in which each student in the dyad had learner control is illustrated. These data were obtained from the analysis of videotape data, which captured student activities during the research sessions.



*Figure 6-5 The percentage of time in which each student had control of the computer (learner control).*

In order to further elaborate on the degree of cooperation and sharing of instructional control, students from dyads were interviewed. In these interviews, it was established that in general students from dyads that utilised the scaffolded worksheets felt that they had an approximately equal share in using the computer and deciding what to look at on the computer [instructional control]. This is illustrated in the following interviews with Dyad 1 that used the scaffolded worksheets.



**Interviewer:** When you were using the computer, did you work well with your partner?

**Student 2:** Yes ... we worked pretty hard.

**Interviewer:** Who used the computer the most?

**Student 2:** ummm ... we pretty much took turns at using it [the computer].

**Interviewer:** How did you decide who would do what?

**Student 2:** We didn't talk about it or anything ... we just took turns. [Student 3] used the computer first and I read and followed the worksheets and then when we had completed it we switched over.

**Interviewer:** Why did you do that?

**Student 2:** So that we both got to use the computer.

**Interviewer:** Why was using the computer important to you?

**Student 2:** ... so we both got to do both things. When I was using the computer, I got to choose what we would do next and when [Student 3] was using the computer he did.

**Interviewer:** Why is that important?

**Student 2:** We both get to do what we want ... its stops us fighting, I guess.

**Interviewer:** How did you decide when to switch over?

**Student 2:** after each worksheet.

*Figure 6-6 Interview A with Student 2*

In the above interview excerpt, Student 2 felt that instructional control was reasonably well shared between within his dyad. This was confirmed by the Researcher and is illustrated in Figure 6-3. His partner shared this view of equal division of tasks.

**Interviewer:** When you were using the computer, did you work well with your partner?

**Student 3:** Yeah .. we worked well.

**Interviewer:** Who used the computer the most?

**Student 3:** both of us ... no-one hogged the computer.

**Interviewer:** How did you decide who would do what?

**Student 3:** I am not sure ... we just took turns. I think I used it first and then [Student 2] had a go and then we switched back.

**Interviewer:** Why did you do that?

**Student 3:** So that we both got to use the computer.

**Interviewer:** Why was using the computer important to you?

**Student 3:** ... so we both had a go.

**Interviewer:** Why is that important?

**Student 3:** We both had a chance to decide what to do.

**Interviewer:** How did you decide when to switch over?

**Student 3:** after each worksheet.

*Figure 6-7 Interview A with Student 3*

In contrast, students from dyads that did not use the scaffolded worksheets, tended to have a more unequal time distribution in the ownership of instructional control. This is illustrated in the following interview with students from Dyad 4.

- Interviewer:** When you were using the computer, did you work well with your partner?  
**Student 6:** Yes.  
**Interviewer:** Who used the computer the most?  
**Student 6:** We shared it.  
**Interviewer:** Equally?  
**Student 6:** Yes ... well we did, but [Student 9] did not really want to use it.  
**Interviewer:** Why do think that is?  
**Student 6:** Not sure ... maybe he's not comfortable using a computer.  
**Interviewer:** How did you decide who would do what?  
**Student 6:** We just took turns.  
**Interviewer:** Why did you do that?  
**Student 6:** To share the computer  
**Interviewer:** Why was using the computer important to you?  
**Student 6:** I like computers and am good with them. I wanted to use the computer so that we could use the program properly.  
**Interviewer:** Do you think that your partner could not use the program properly?  
**Student 6:** .....no.  
**Interviewer:** When did you switch with him in using the computer?  
**Student 6:** When I thought that he wanted a go.

*Figure 6-8 Interview A with Student 6*

- Interviewer:** When you were using the computer, did you work well with your partner?  
**Student 9:** Yes.  
**Interviewer:** Who used the computer the most?  
**Student 9:** He did.  
**Interviewer:** Why do think that is?  
**Student 9:** Not sure ... I didn't mind at first, but then it annoyed me.  
**Interviewer:** Did you say anything to him?  
**Student 9:** No  
**Interviewer:** Why not?  
**Student 9:** Didn't think that it was a major problem and if he was happy doing that ... so what.  
**Interviewer:** Why was using the computer important to you?  
**Student 9:** I would have liked to look at some of the program more.

<b>Interviewer:</b>	Why didn't you?
<b>Student 9:</b>	By the time that I had thought of looking at something else [Student 6] had already moved on to something else.
<b>Interviewer:</b>	Why didn't you ask for him to go back or look at what you wanted to look at?
<b>Student 9:</b>	Sometimes I did and other times I figured that it wasn't a big issue so I didn't worry about it.

*Figure 6-9 Interview A with Student 9*

### **Discussion and Assertions**

These data have implications for the manner in which the collaborative learning environment is managed, especially, if one student in a collaborative pair retains the majority of the learner control and also has instructional control. The data suggests that the scaffolded dyads appeared to have a greater willingness to share the responsibility of learner control compared to the non-scaffolded dyads. This may be the result of the printed worksheet signalling an end to a particular component of the work and an opportunity for change was implied, as opposed to an uninterrupted exploration of the program in the non-scaffolded dyads. This facet of the student collaboration within the IMM environment requires further research and investigation.

The creation of a learning environment in which students possess a degree of autonomy and responsibility in the learning process is considered to be critical to learning success (Oliver, Omari & Herrington, 1998). Such individual autonomy is reduced in collaborative learning environments when small groups are responsible for the shared decisions that affect the direction and engagement of the group's learning. The quality and nature of such collaborative interactions may therefore have an impact on the learning of small groups using IMM software.

Tao and Gunstone (1997) investigated the conceptual changes that took place when dyads of students worked collaboratively using physics simulations from a computer program. These researchers measured the nature and extent of collaboration in terms of students' joint on-task behaviour; equality of engagement and mutuality of engagement.

While these researchers focussed on the social-cognitive factors that affect learning, few have examined the more specific aspect of ownership of instructional decisions.

In the research undertaken, it was found that dyads in the scaffolded group shared the responsibility of learner control more evenly than those in the non-scaffolded group. This was accompanied, in the majority of situations, with these students possessing the ownership of instructional control. This suggests that physical manipulation of navigation through the IMM software was accompanied with a greater responsibility for the decisions about navigation. This suggests that dyads in which such instructional control was evenly shared, provided an environment in which there was a greater equality of collaboration in the navigation of such software.

The evidence from this study permits the following assertions (6.8 - 6.9) to be made.

***Assertion 6.8***

***In general, students in the scaffolded dyads shared the responsibility for mouse control more equitably than those students in the non-scaffolded dyads.***

***Assertion 6.9***

***In general, students that exercised mouse control also maintained the ownership of instructional control.***

While the engagement of such dyad interactions is essential to the nature and degree of collaboration (and will be discussed in a later section), the equality of the decision-making process of such navigation, with respect to the instructional path affects the manner in which students are exposed to different parts of the IMM program. Decisions about

specific instructional paths determines whether students access appropriate material in a sequence that maximises learning opportunities.

### Instructional Time

The amount of time devoted to the IMM software and required tasks during the instructional sessions was calculated by timing the various student interactions from the videotape data. These data were analysed and compared between the scaffolded and non-scaffolded dyads.

The total amount of time devoted to using the IMM software for all dyads over the three sessions in which students used the software is shown in Figure 6-4. This Table shows that the scaffolded dyads spent on average 30 minutes longer utilising the IMM software over the three sessions compared to the non-scaffolded dyads.

Table 6-5

*The total time in minutes devoted to the IMM software by dyads over the three sessions and the average times devoted by the scaffolded and non-scaffolded dyads.*

	Dyad	Time (min)
Scaffolded Dyads	1	145
	2	137
	3	154
	Average	145
Non-Scaffolded Dyads	4	113
	5	113
	6	120
	Average	115

### **Discussion, Assertions and Observations**

A comparison of the time spent using the IMM software between the scaffolded and non-scaffolded dyads indicates that dyads that utilised the scaffolded instruction had a greater time engagement with the IMM software. Scaffolded dyads tended to work longer on a smaller number of exercises as they accessed the Demonstration and Simulation modules more frequently than non-scaffolded dyads. Scaffolded dyads tended to work independently of the remaining dyads in the room. In contrast, dyads in the non-guided group tended to have shorter engagement times and were influenced by the time engagement of other dyads. These students tended to work on exercise tasks quickly (illustrated in Table 6-2), completing more exercises (although often not utilising the full potential of the various instructional paths) and tended to browse much more, and then use the completion of other dyads to end their own engagement with the tasks.

The evidence from this study permits the following observations (6.10 - 6.11) to be made.

#### ***Observation 6.10***

*Students in the scaffolded dyads devoted more time to the IMM software than those in the non-scaffolded dyads.*

#### ***Observation 6.11***

*Students in the non-scaffolded dyads managed to complete more exercises than those in the scaffolded dyads.*

## Chapter Summary

The assertions and observations developed through this chapter are summarised below:

- 6.1 *Students in the scaffolded dyads utilised instructional paths for all exercises attempted from a macroscopic, particulate to a symbolic level of analysis.*
- 6.2 *Some students in the scaffolded dyads developed an appreciation, at a metacognitive level of how the various levels of representation contributed to their understanding of the chemical reactions and to their ability to balance the chemical equation.*
- 6.3 *On average, students in the scaffolded dyads viewed the Demonstration and Simulation modules for the various reactions more frequently than those in the non-scaffolded dyads.*
- 6.4 *Students in the scaffolded dyads moved from worksheets with higher levels of scaffolding to those with lower levels of scaffolding as they gained experience, success and confidence.*
- 6.5 *Students in the non-scaffolded dyads utilised instructional paths in an irregular manner that did not support the conceptualisation of the reaction from the macroscopic to particulate and finally to the symbolic form.*
- 6.6 *Some non-scaffolded student dyads did not utilise the Demonstration and/or Simulation modules for all of the exercises attempted.*
- 6.7 *Scaffolding worksheets are needed to guide students through an appropriate learning pathway involving all of the modules.*

- 6.8 *In general, students in the scaffolded dyads shared the responsibility for mouse control more equitably than those students in the non-scaffolded dyads.*
- 6.9 *In general, students that exercised mouse control also maintained the ownership of instructional control.*
- 6.10 *Students in the scaffolded dyads devoted more time to the IMM software than those in the non-scaffolded dyads.*
- 6.11 *Students in the non-scaffolded dyads managed to complete more exercises than those in the scaffolded dyads.*



## **CHAPTER 7**

### **RESULTS AND DISCUSSION**

#### **STUDENT INTERACTION AND COLLABORATION WHILST USING THE IMM SOFTWARE**

##### **Introduction**

This Chapter presents and interprets the data related to the nature of students' collaboration and interactions with the IMM software. Particular attention is paid to the nature and degree of collaboration and equality of IMM interaction. These data were obtained by analysing video capture of screen access, participant survey and were confirmed by the Researcher observation and notes. These data are discussed and then several assertions are made related to this theme of student interaction and collaboration whilst using the IMM software.

A number of frameworks have been utilised in research to investigate the interactions that occur within learning environments. In an IMM learning environment interactions occur between the teacher, learners and between them and the IMM software. These interactions have been introduced and summarised in Figure 2-4.

While much research has focussed on the interactions between learners and the IMM environment (Windschitl & Andre, 1998; Lee & Heller, 1997; Horiwitz & Feurzeig, 1994), little attention has been paid to the interactions that occur between the learners in this environment. One focus of this research was on the interaction between students and the nature and extent of these interactions.

Student interactions were videotaped and then analysed against the peer collaboration factors as utilised by Tao and Gunstone (1997), to identify the nature of student interactions and their degree of collaboration. The peer collaboration factors considered included:

- Joint on-task engagement (working together rather than individually);
- Equality of engagement (the degree to which each is equally involved in learning); and
- Mutuality of engagement (the degree to which there is co-construction of knowledge in comparison with individual knowledge construction), with high mutuality indicating "extensive, connected and intimate discourse" and low mutuality indicating "limited, unconnected discourse" with each student not publicly making their ideas known.

As per the work of Tao and Gunstone (1997), joint on-task engagement, a necessary condition for collaboration, was taken to be the percentage of tasks on which students in the dyad worked together, with over 80% regarded as high, 60-80% regarded as medium and less than 60% as low. The arbitrary categorisation of high, medium and low was used to permit comparisons between the dyads. Tasks completed by dyads were videotaped and conversational interaction recorded and analysed to determine whether students in the dyad worked together or in isolation. The conversational interactions were further examined to make inferences regarding whether the equality and mutuality of engagement were high, medium or low. The inferences of the equality of engagement were based on an interpretive assessment of the collaborative sequences by the Researcher, rather than counting of occurrences of certain events or utterances. These data are summarised in Table 7-1.

*Table 7-1*  
Characteristics of collaboration

	Dyads	Joint on-task engagement (% tasks; total no.)	Equality of engagement	Mutuality of engagement
Scaffolded dyads	1	High (92%; 22/24)	High	medium
	2	High (94%; 30/32)	High	high
	3	High (100%; 19/19)	High	high
Non-scaffolded dyads	4	Low (41%; 14/34)	Low *Student 10	low
	5	Low (56%; 18/32)	medium *Student 8	low
	6	Low (49%; 18/37)	medium *Student 6	medium

Note: \* indicates the student that contributed the most to the task, when the equality of engagement was considered to be medium or low.

The analysis of the various characteristics of collaboration for each dyad indicates that the joint on-task engagement for each of the scaffolded dyads was considered to be high, with engagement for each group calculated to be equal to or greater than 92%. In comparison, the joint on-task engagement values for the non-scaffolded dyads were found to be between 41 – 56%. With respect to the equality of engagement, Dyads 1, 2 and 3 were considered to be high, whereas Dyads 5 and 6 were considered to have medium equality, and Dyad 4 was considered to be low. The final characteristic of collaboration, the mutuality of engagement shows an interesting pattern, with only Dyads 2 and 3 considered to be high, Dyads 1 and 6 considered to be medium and Dyads 4 and 5 considered to be low in their engagement. These characteristics of collaboration will now be considered in greater detail within the structure and limitations of each individual dyad.

### Dyad 1

This Dyad, comprising Students 11 and 4 worked well together. They collaborated with little or no restriction and managed to complete six of the 11 exercises available in the Molecular Equation module with the IMM software and six of the exercises available in the Interpreting Equation module. These students completed the tasks with care and made an effort to move from the worksheet with the greatest amount of scaffolding to that with the least, as shown in Table 6-3. Their equality of engagement was high, with both students contributing in reasonably equal proportions, to the discussion at hand. Both students appeared motivated to participate and actively interacted with each other and the IMM software. Although these students worked collaboratively in terms of the measures of both joint on-task and equality of engagement, their discourse varied from in-depth discussions about the nature of the task to short, abrupt sequences of interactions in which there was little discussion of their ideas and thoughts. These modes of collaboration are illustrated in the following excerpts.

- |             |                                                                                                              |
|-------------|--------------------------------------------------------------------------------------------------------------|
| Student 11: | Select one that we could do (pointing to the screen).                                                        |
| Student 4:  | How about just doing them in order?                                                                          |
| Student 11: | Ok.                                                                                                          |
| Student 4:  | The sheet says to watch the video.                                                                           |
| Student 11: | (accesses demonstration)                                                                                     |
| Student 4:  | Now replay it and we have to get the names of the reactants.                                                 |
| Student 11: | What are reactants?                                                                                          |
| Student 4:  | They are the chemicals that take part in a reaction ... they are the things that are there at the beginning. |
| Student 11: | You mean starting chemicals?                                                                                 |
| Student 4:  | Yeah                                                                                                         |
| Student 4:  | The reactants are hydrogen and chlorine.                                                                     |
| Student 11: | Got it ... did you get the product?                                                                          |
| Student 4:  | I think she said (audio) hydrogen chloride gas ... but I'm not sure. (watch demonstration)                   |
| Student 11: | Yeah ... hydrogen chloride.                                                                                  |
| Student 4:  | We need to watch it again and this time get the colours of each chemical (watch demonstration)               |
| Student 11: | hydrogen – colourless, chlorine-greenish yellow and hydrogen chloride is colourless.                         |

Figure 7-1 Interaction sequence A with Dyad 1 (within the Molecular Equation module)

- Student 11:** Did you see those white dots move?
- Student 4:** Which ones?
- Student 11:** Repeat the movie (watch simulation).  
Now watch the white dots (watch simulation).
- Student 4:** There supposed to be the nucleus.
- Student 11:** No ... wait to the movie is over ... watch for the magnesium and oxygen atoms colliding ... see ... the white dots are different and they move (watch simulation).
- Student 4:** You're right ... I thought I saw those dots in the last video (previous example)  
(selects Nitric oxide and Oxygen gas example and plays simulation)  
The dots here are small and not so bright ... I thought they represent the nucleus (watch simulation).
- Student 11:** So did I ... but what are the other ones ... atoms nucleuses can't move.
- Student 4:** (watch simulation)  
She said that they were electrons ... that makes sense ... electrons move from the magnesium to the oxygen atom, right?
- Student 11:** Yeah.
- Student 4:** and the white dots came from the outside of the atoms and that's where electrons are.
- Student 11:** and when they left the magnesium, it got smaller because it had less electrons and the oxygen got bigger cause it had more electrons.
- Student 4:** That's right.
- Student 11:** So magnesium goes to two plus and has 2, then 8 electrons and O goes from two and six electrons to two and eight.
- Student 4:** Yeah ... but that's not bigger.
- Student 11:** Yes it is two, six to two, eight?
- Student 4:** Why does it get bigger then?
- Student 11:** What do you mean?
- Student 4:** You're only putting two more electrons in the shell, not making more shells ... so the atom shouldn't get bigger.
- Student 11:** Course it does ... think ... if you put two more footy's in a bag, wouldn't the bag get bigger?
- Student 4:** It's not the same!
- Student 11:** Why not? (silence for 35s)
- Student 4:** Maybe the shells move further apart?
- Student 11:** Well ... there are more electrons there – may be they push the shells apart due to repulsion.
- Student 4:** That's possible. I'm OK with that

*Figure 7-2 Interaction sequence B with Dyad 1 (within the Molecular Equation module)*

<b>Student 4:</b>	One $N_2$ and three $H_2$ 's gives two $NH_3$ 's (selects two ammonia molecules and places them in the 'after reaction box')
<b>Student 11:</b>	That's wrong.
<b>Student 4:</b>	Why?
<b>Student 11:</b>	It says that "in this reaction two molecules of $N_2$ react with 6 molecules of $H_2$ to produce four molecules of $NH_3$ . Check the number of molecules of ammonia."
<b>Student 4:</b>	So there should be four?
<b>Student 11:</b>	Guess so?
<b>Student 4:</b>	(places another two ammonia molecules in the 'after reaction box' and then checks answer) Good ... let's move on!

*Figure 7-3 Interaction sequence C with Dyad 1 (within the Interpreting Equation module)*

Figure 7-1 illustrates an interaction sequence A between the students of Dyad 1. In this sequence, the students appeared to be friendly and supportive towards each other. Both students appeared to be working in such a manner that no one student was solely responsible for the decision-making process and they worked with a high degree of equality, in terms of their engagement. The sequence also indicates that the students were jointly working on the task at hand and assisting each other to select the relevant information from the simulation sequence, as required by the scaffolded worksheets.

In Figure 7-2, the interaction sequence illustrates that the students once again assisted each other in selecting relevant information from the simulation. This was evident when Student 11 became concerned about the identity of the 'white dots'. This student initiated an investigative discussion, in which the dyad viewed previously seen simulations and then compared them with the one at hand. Through discussion these students co-constructed an understanding that the 'white dots' were electrons that were moving from one particle to another. Once this was accepted, Student 4 became concerned that such a movement in electrons from one particle to another, could not totally account for the change in the size of the particles pre and post- electron movement experienced during the simulation. This concern resulted in peer conflict, in that both students could not agree on a reason for the physical size change in the particles. The students worked together, by discussing the idea, with Student 11 proposing an analogy to assist the other student. This

analogy was not convincing and the students maintained their difference in opinion. Finally, Student 4, prompted further discussion, by proposing an alternative suggestion, which resulted the co-construction of knowledge and conceptual change in both students. This sequence illustrates a high degree of mutuality, in terms of their engagement, in which student discussion was interconnected, with each student expressing their ideas and opinions contributing to the co-construction of new understanding. In comparison, Figure 7-3, illustrates an interaction sequence in which the students displayed a lack of concern for the reasoning behind the answer and appeared willing to simply accept the feedback prompted by the IMM software. The discussion in this sequence appeared more expository in nature than in their previously reported interaction sequence.

## **Dyad 2**

This Dyad, consisting of Students 2 and 3, worked well together. They collaborated with little or no restriction and managed to complete six of the 11 exercises available in the Molecular Equation module with the IMM software and all of the exercises available in the Interpreting Equation module. These students completed the tasks with care and made an effort to move from the worksheet with the greatest amount of scaffolding to that with the least, as shown in Table 6-3. Their equality of engagement was high, with both students contributing in approximately equal proportions, to the discussion at hand. Both students appeared motivated to participate and actively interacted with each other and the IMM software. Both of these students tended to initiate and participate in discussions related to the nature of the task. In general, their discourse involved a discussion about the problem or exercise under investigation and involved each student presenting their idea and then substantiating their position. This level of discourse tended to be more extensive and connected, although at times, this dyad did present short, abrupt sequences of interactions in which there was little discussion of their ideas and thoughts. These modes of collaboration are illustrated in the following excerpts.

**Student 2:** Let's do the hydrogen peroxide one.  
**Student 3:** OK (selects the hydrogen peroxide decomposition example – plays demonstration)  
**Student 2:**  $\text{H}_2\text{O}_2$  ... isn't that the stuff that you can put in your hair to bleach it?  
**Student 3:** Yeah ... think so ... but I'm not sure how it does it? (play demonstration)  
**Student 2:** The name of the reactants are hydrogen peroxide and manganese dioxide.  
**Student 3:** No ... I think that there is only one reactant in this one.  
**Student 2:** No she added manganese powder to the hydrogen peroxide liquid.  
**Student 3:** But the manganese is only a catalyst ... remember ... they make reactions go faster, but don't actually react.  
**Student 2:** If it doesn't react, then why is it added?  
**Student 3:** Don't know ... it just makes things go faster.  
**Student 2:** Play the demo again.  
**Student 3:** See ... the black powder is still there (at the end of the reaction).  
**Student 2:** That doesn't mean anything. The video could have stopped early or there is more there than needed.  
**Student 3:** Yeah Ok ... but catalysts don't react. What else do we need to know?  
**Student 2:** The products ... oxygen and water.  
**Student 3:** Colour of oxygen is clear and so is water ... hang on ... they are colourless, clear means that you can see through them.  
**Student 2:** Play the simulation?  
**Student 3:** (nods head)  
**Student 2:** ... that's cool ... look at them (the molecules) shake.  
**Student 3:** Vibrate. Yeah better than looking at a book.  
**Student 2:** Play it again? (play demonstration twice) The formula of hydrogen peroxide is  $\text{H}_2\text{O}_2$ , water is  $\text{H}_2\text{O}$  and oxygen is  $\text{O}_2$ . All finished?  
**Student 3:** Yeah sort of ... look at the beaker there was no manganese there.  
**Student 2:** What?  
**Student 3:** There was no manganese in the beaker ... I told you it can't be a reactant.  
**Student 2:** Play it again. (play demonstration). OK you're right  
**Student 3:** See it is needed to make the reaction go faster, but doesn't react.  
**Student 2:** Fine, I still think that must do something ... it can't simply do nothing and still make the reaction faster ... How does it make the reaction faster?  
**Student 3:** Don't know ... it just does ... but we don't have to know this for the question.  
**Student 2:** OK ... let's do the next one.

Figure 7-4 Interaction sequence B with Dyad 2 (within the Molecular Equation module)



Student 2:	Try this ... there are two $N_2$ molecules and each ammonia has only one nitrogen atom ... therefore we need four ammonias.
Student 3:	But why nitrogen?
Student 2:	Why not?
Student 3:	Why not look at hydrogen ... there are seven of them.
Student 2:	one, two, three ... no there are eight hydrogens.
Student 3:	Yeah OK ... that means that there are 16 hydrogens [atoms].
Student 2:	So?
Student 3:	In your box you have 12 (pointing to the after reaction box).
Student 2:	So I'm right ... we have 16 but I only need 12 of them.
Student 3:	What happens to the other four?
Student 2:	Nothing (checks answer) What? ... there's nothing wrong with the number of hydrogens (counts the number of hydrogens again; checks answer again – no response)
Student 3:	Try to get rid of some of the hydrogens from the first box.
Student 2:	How?
Student 3:	Drag and drop.
Student 2:	OK ... (attempts to move a hydrogen molecule from the 'before reaction box') ... no doesn't work ... maybe put two extra ones here (points to the after reaction box; adds two hydrogen molecules to the 'after reaction box'; checks answer) ... good!
Student 3:	Why put them there ... they didn't react?
Student 2:	Exactly ... there were left over.
Student 3:	But shouldn't they be shown in the equation then?
Student 2:	Don't know (grunt – unable to decipher)
Student 3:	The equation only shows the chemicals reacting doesn't it? That's why we didn't include the manganese dioxide in that equation ... it was a catalyst.
Student 2:	Yeah ... but this looks like it is asking for all those things in the box before the things react and then what is left in the box after the reaction.
Student 3:	That means that we not really writing an equation here.
Student 2:	Guess so ... the boxes show what we have and the equation is only those that react.

Figure 7-5 Interaction sequence C with Dyad 2 (within the Interpreting Equations module)

Figure 7-4 illustrates interaction sequence A between the students of Dyad 2. In this sequence the students appeared to be friendly and supportive to each other. The interaction sequence also illustrates that both students took an active role in the decision-making

processes, were involved in navigational control and worked with a high degree of equality, in terms of their engagement.

The interaction sequence also indicated that the students had some concept of the use of one chemical (hydrogen peroxide), referred to in the IMM software. This indicates an attempt at relating the relatively unfamiliar laboratory and IMM environments to their everyday lives. Further, the students discussed the use of one chemical (manganese dioxide) as a catalyst in the reaction and debated whether or not it should be included in the reaction. In this interaction, the students utilised both the Demonstration and Simulation modules of the IMM software to add support to their argument or provide evidence against their ideas. Unfortunately, they were unable to come to a scientifically correct answer to their question due to an inadequate knowledge of the chemistry of catalysts, however, they clearly showed interest in this problem and made an effort to obtain an answer from discussion and use of the IMM software.

In Figure 7-5, the students actively worked together to complete an exercise in the Interpreting Equation module in the IMM software. In this sequence, the students worked jointly on the task and initiated discussions aimed at helping the dyad work through the exercise together. Students did not simply state an opinion, but rather provided supportive arguments and statements, including relating the current example to one completed earlier, to assist each other's learning.

This dyad illustrated a high degree of collaboration on all indices and often raised discussion, which went beyond the scope of the IMM software. Although some of these discussions resulted in unresolved issues, the students were operating at a higher level of cognition and attempted to come to a conclusion by relating various concepts to each other. This approach resulted in a high degree of mutuality during their interactions with few expository sequences.

### Dyad 3

This Dyad, consisting of Students 5 and 1 worked well together. They collaborated with little or no restriction and managed to complete four of the 11 exercises available in the Molecular Equation module with the IMM software and all of the exercises available in the Interpreting Equation module. The last two exercises in the Interpreting Equation module were rushed and were not completed with the same effort or level of interaction as the previous exercises. This contrast in effort was considered to be due to the time constraints of the available work sessions and as a result was not considered in the evaluation of the Dyad's mode of collaboration. These students completed all other tasks with care but appeared reluctant to utilise worksheets with minimal scaffolding, as shown in Table 6-3. Their equality of engagement was high, with both students contributing in approximately equal proportions, to the discussion at hand. Both students appeared motivated to participate and actively interacted with each other and the IMM software. Both of these students tended to initiate and participate in discussions related to the nature of the task. In general, their discourse involved a discussion about the problem or exercise under investigation and involved each student presenting their idea and then substantiating their position. This level of discourse tended to be more extensive and connected, although at times, this dyad did present short, abrupt sequences of interactions in which there was little discussion of their ideas and thoughts. These characteristics of collaboration are illustrated in the following excerpts.

- |            |                                                                             |
|------------|-----------------------------------------------------------------------------|
| Student 1: | Do you want to use the computer first?                                      |
| Student 5: | No ... you can ... let's just share.                                        |
| Student 1: | How about one exercise each?                                                |
| Student 5: | OK.                                                                         |
| Student 1: | I'll go first ... let's do this one.                                        |
| Student 5: | Play the demo first.                                                        |
| Student 1: | (plays demo) That's brilliant ... fantastic!                                |
| Student 5: | Cool ... did you see that gas move ... it looked like a flame.              |
| Student 1: | Let's watch it again and get the name of the chemical reacting with oxygen. |
| Student 5: | It's on the heading – nitric oxide.                                         |
| Student 1: | OK – got it.                                                                |
| Student 5: | Did you get the name of the products?                                       |

<b>Student 1:</b>	No ... watch it again.
<b>Student 5:</b>	That is so cool ... the product is nitrogen dioxide.
<b>Student 1:</b>	Grunt (unable to decipher)
<b>Student 5:</b>	We need to replay it and get the colour of everything.
<b>Student 1:</b>	That's OK ... everything is colourless except the brown gas which is nitrogen dioxide.
<b>Student 5:</b>	Let's just check (play demonstration again) Yeah you're right ... nitric oxide, oxygen are colourless and nitrogen dioxide is brown.
<b>Student 1:</b>	What's the formula of nitric oxide?
<b>Student 5:</b>	Don't know ... she didn't say [audio].
<b>Student 1:</b>	Why do you think the brown gas moved down like that? More dense?
<b>Student 5:</b>	Was the jar full of nitric oxide or did it contain oxygen?
<b>Student 1:</b>	Must be full otherwise the reaction would have started before she took the lid off.
<b>Student 5:</b>	Play it again.
<b>Student 1:</b>	See it starts at the top.
<b>Student 5:</b>	That's where the nitric oxide reacts with the oxygen outside the container ... but that doesn't explain why it moves down [the gas container].
<b>Student 1:</b>	Gas particles move right?
<b>Student 5:</b>	Yeah.
<b>Student 1:</b>	Maybe the oxygen diffuses into the gas jar and as it moves down it hits more nitric oxide and the reaction continues.
<b>Student 5:</b>	That would explain why the bottom bit of the brown gas moves downwards ... but not why it gets darker in the middle ... unless the gas in the jar is diffusing as well and the dark colour is where the two gases meet and form $\text{NO}_2$ .
<b>Student 1:</b>	That's it ... we're good!

*Figure 7-6 Interaction sequence A with Dyad 3 (within the Molecular Equations module)*

Figure 7-6 illustrates interaction sequence A between the students of Dyad 3. In this sequence, the students were friendly and supportive of each other. They worked jointly on all tasks and had a high degree of equality, of engagement, even though the navigational control was shared somewhat disproportionately as illustrated in Figure 6-3.

This sequence also illustrates that the interaction between the students had a high degree of equality and that the interaction involved an in-depth discussion on one of the demonstration sequences from the IMM software. In this discussion the student utilised their understanding of the kinetic theory of gases to discuss and account for the various

observations that they made relating to the demonstration. These students rarely interacted in simple expository terms but rather initiated and participated in a number of discussions in order to understand or explain their thoughts and ideas on particular concepts.

#### **Dyad 4.**

This Dyad, consisting of Students 10 and 12 worked together with no conflict and appeared to be friendly and cooperative, however, they did not collaborate well and scored poorly on each of the three indicators of collaboration. With respect to their joint on-task engagement, they only appeared to work collaboratively on 14 of the 34 exercises completed. On these 14 tasks, they shared ideas and discussed answers, however, such discourse was not present on the remaining tasks. Although both students did participate, Student 12 often appeared disinterested and tended to communicate with his partner less as the working sessions proceeded. This student, although present for all working sessions, did not complete the posttest. This lack of interest may have been the result of a lack of motivation or may have been the result of inequity in the ownership of instructional control, as discussed in Chapter 6 and illustrated by Figure 6-3. As a result of their interactions, their equality of engagement was considered to be low. The discourse between the students tended to be quite unconnected, with little discussion of the exercises at hand and centred around a simple presentation of ideas, typically, by only Student 10. These modes of collaboration are illustrated in the following excerpts.

<b>Student 10:</b>	Which one should we do first?
<b>Student 12:</b>	Whatever you choose.
<b>Student 10:</b>	Fine ... hydrogen and chlorine and play demo.
<b>Student 12:</b>	That's good ... play it again.
<b>Student 10:</b>	(plays demo again) grunt [unable to decipher]
<b>Student 12:</b>	Do it again.
<b>Student 10:</b>	No ... we've seen it twice already ... simulation now (plays simulation). That's pretty good.
<b>Student 12:</b>	It's OK.
<b>Student 10:</b>	(plays simulation again) now do the equation ... hydrogen is H (presses enter) ... that's not wrong (presses enter) ... this is stupid.
<b>Student 12:</b>	Put a two in there.
<b>Student 10:</b>	I knew that ... and Cl will be the same ... good ... HCl ... good and to balance put a two in front of HCl. Do you want to do one now?

**Student 12:** No. I'll watch.  
**Student 10:** OK. Magnesium and oxygen, that's a good reaction (play demo) ... fantastic.  
**Student 12:** mmmm  
**Student 10:** Don't you think that's great?  
**Student 12:** It's OK ... let's just hurry up.  
**Student 10:** No ... I want to watch it again (plays demonstration twice)  
**Student 12:** Don't worry about the simulation ... it's just like a cartoon ... just do the equation.

Figure 7-7 Interaction sequence A with Dyad 4 (within the Molecular Equations module)

**Student 10:** That's a pretty good demo.  
**Student 12:** Yeah.  
**Student 10:** How can two colourless liquids make a yellow liquid?  
**Student 12:** It's not a yellow liquid ... she said it was a yellow solid.  
**Student 10:** OK ... but how can that happen?  
**Student 12:** When things mix different chemicals join together to make different things ... and sometimes these things have different colours. Just like adding that indicator ... mmm ... phenol [phenolphthalein] to acid and base ... same thing.  
**Student 10:** I'll play the simulation.  
**Student 12:** See how some chemicals are there but don't react ... and when you mix some chemicals some of them join together. That's why.  
**Student 10:** Will they always join if near each other?  
**Student 12:** Yeah ... they attracted to each other ... lead is positive and iodine is negative.

Figure 7-8 Interaction sequence B with Dyad 4 (within the Molecular Equations module)

<b>Student 10:</b>	Move one, two, three, four ammonias in the box, cause there are four nitrogens there first (checks answer) ... not right ... why? ... four nitrogens here and four here, 16 hydrogens here and 16 here ... Oh only 12 here! Need to remove four from here (before reaction box) ... can't ... why? (checks once again) number of hydrogens is wrong. If I can't remove them, maybe ... (adds two hydrogen molecules to the after reaction box) ... that works! Don't see why ... why does hydrogen produce hydrogen?
<b>Student 12:</b>	Come on hurry up!
<b>Student 10:</b>	OK!

*Figure 7-9 Interaction sequence C with Dyad 4 (within the Interpreting Equations module)*

Figure 7-7 illustrates interaction sequence A between the students in Dyad 4. In this sequence, the students appeared to be communicating in quite friendly terms; however, there appears to be little collaboration. The individual students did not appear to consider each others request for particular instructional paths and without consultation, Student 10, who had navigational and instructional control for much of the time, followed his own interests. The interaction sequence also illustrates that much of Student 10's interactions were procedural in nature – a type of 'talk-aloud-protocol'. His interactions towards Student 12 tended to be directed towards seeking affirmation of his ideas or thoughts. There was very little true discussion between the students.

Figure 7-8 illustrates one interaction sequence that did generate discussion. This sequence illustrates that the students had the potential to work together and assist each other by talking through ideas, although in this sequence it can be seen that Student 10 provided little input and did not appear to readily accept the thoughts of his partner.

The interaction sequences between these students appeared to lack any real depth and were more procedural in nature. This was not conducive to collaborative learning. Further, it appeared that many events that were unexpected were not discussed within the dyad and merely accepted, as opposed to discussed and investigated. An example of such mere acceptance was illustrated in Figure 7-9.

### Dyad 5

This Dyad, consisting of Students 8 and 9 worked together with no conflict and appeared to be friendly and cooperative, however, they did not collaborate well and scored poorly on two of the three indicators of collaboration. With respect to their joint on-task engagement, they only appeared to work collaboratively on 18 of the 32 exercises completed. On these tasks, they shared ideas and discussed answers, however, such discourse was not present on the remaining tasks. On these tasks, the student that presented his thoughts or explained his actions was typically the student that had the ownership of instructional control. This student dictated which exercise was to be done and then proceeded to talk through the exercise with little two-way discussion. Although the mutuality of the engagement was low, there was a reasonable degree of equality of engagement shown on most tasks, and on those considered to be low in equality, the dominant student in the engagement (Student 8) was the one considered to have the ownership of instructional control, as described in Chapter 6. These modes of collaboration are illustrated in the following excerpts.

Student 8:	Let's do the iron and chlorine one.
Student 9:	Sounds good.
Student 8:	Play demo.
Student 9:	That looks like steel wool ... it is ... she said it is.
Student 8:	Iron must be the same as steel wool.
Student 9:	Guess so ... or steel wool is made from iron.
Student 8:	Same difference!
Student 9:	Pretty good reaction.
Student 8:	Yeah originally it looked like a gas and then all the solid stuff fell to be a solid.
Student 9:	That's like smoke ... solid particles held up in the air.
Student 8:	Look at the simulation?
Student 9:	Yeah.
Student 8:	(play simulation) Looks like the iron is solid ... everything is close together but the chlorine are further apart.
Student 9:	Yeah, but the iron chloride particles are not squeezed together ... yet their supposed to be a solid.
Student 8:	Maybe that's as close as they can get.
Student 9:	Maybe.

Figure 7-10 Interaction sequence B with Dyad 5 (within the Molecular Equations module)



<b>Student 8:</b>	Shall we do this one? [lead iodide precipitation]
<b>Student 9:</b>	Whatever?
<b>Student 8:</b>	(press demo)
<b>Student 9:</b>	Turn up the volume.
<b>Student 8:</b>	Looks good eh? (presses simulation) Good. (presses equation) OK ... lead nitrate is Pb bracket N O 3
<b>Student 9:</b>	NO ... this is poor, it should be ...Pb two positive plus two I negative forming Pb I two.
<b>Student 8:</b>	Why? Where did you get all that from?
<b>Student 9:</b>	It just is?
<b>Student 8:</b>	OK ... I'll do another.

*Figure 7-11 Interaction sequence C with Dyad 5 (within the Molecular Equations module)*

Figure 7-10 illustrates interaction sequence A between the students of Dyad 5. In this sequence, the students appear to be friendly and working collaboratively with each other. The sequence illustrates a high degree of equality within the interaction and a preparedness to discuss their ideas as opposed to simple statements with little or no supportive arguments, as shown in Figure 7-11. This interaction sequence was however, a rarity, with the vast majority of interactions indicating a poor degree of mutuality. In these remaining sequences, the students tended to work independently on the tasks at hand, with Student 8 being the dominant user of the computer and hence navigational control.

Student 9 often illustrated a very good understanding of the exercises under study, which is also indicated by his responses to paper and pencil testing, reported in Chapters 4 and 5. This student however, appeared willing to answer any question asked of him by his partner, but did not freely provide support to his partner or help him to achieve a better understanding of the examples covered.

### **Dyad 6**

This Dyad, consisting of Students 6 and 7 worked together with no conflict and appeared to be friendly and cooperative, however, they did not collaborate well and scored poorly on one of the three indicators of collaboration and only satisfactory on the remaining two. With respect to their joint on-task engagement, they only appeared to work

collaboratively on 18 of the 37 exercises completed. On these tasks, they shared ideas and discussed answers, however, such discourse was not present on the remaining tasks. Although both students did participate, Student 7 often appeared disinterested and at times tended to avoid presenting his ideas and thoughts. This student often appeared to lack confidence and was comfortable for his partner to use the computer on the majority of occasions, as illustrated in Figure 6-3. This lack of confidence may have been the result of his difficulty with the conceptual struggle of being able to understand, balance and interpret chemical equations as is evident by his responses illustrated in Chapters 4 and 5. Notwithstanding these perceived difficulties and lack of confidence, this student made a real effort to participate and interact with his partner and as a result, both their equality and mutuality of engagement was considered satisfactory. These modes of collaboration are illustrated in the following excerpts.

- |                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Student 6:</b> | Do you want to do this one?                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Student 7:</b> | No ... it's alright ... you can.                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Student 6:</b> | OK ... just say if you change your mind? Do this one [magnesium and oxygen gas] (play demo) ... good.                                                                                                                                                                                                                                                                                                                                                           |
| <b>Student 7:</b> | That's a good reaction.                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Student 6:</b> | It doesn't look like magnesium though.                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Student 7:</b> | What doesn't?                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Student 6:</b> | The magnesium.                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Student 7:</b> | How?                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Student 6:</b> | It's very dark compared to the stuff that we get?                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Student 7:</b> | Maybe it's already reacted and that's why it's dark.                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Student 6:</b> | What would it have reacted with? It should have come in a box or something.                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Student 7:</b> | Good point. Don't know.                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Student 6:</b> | How about another ? ... Iron and chlorine?                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Student 7:</b> | You do this one.                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Student 6:</b> | (plays demonstration) Cool reaction. Simulation (plays simulation) That's pretty good ... look at the white dots move ... just like lasers Check out the equation? (enters equation – struggles with computer control; enters all formula; presses enter)[audio feedback – equation not balanced] How do I do this one? Need three chlorines ... times that [iron III chloride] by two, then that [chlorine] by three and the iron by two (presses enter) good. |

**Student 7:** You did well, I think that you have to look for the lowest common factor here to make sure that the number of atoms on each side is equal.

*Figure 7-12 Interaction sequence A with Dyad 6 (within the Molecular Equations module)*

**Student 6:** Start with four moles of  $N_2$ , 15 of  $H_2$  ... need to get how many ammonias? Eight molecules of  $NH_3$ , which means all 4  $N_2$ 's reacting with only 12  $H_2$ 's (presses enter) Yeah ... I did it.

**Student 7:** Well done.

**Student 6:** Do the next one.

**Student 7:** No ... you do it.

**Student 6:** Come on ... I'm doing all of them.

**Student 7:** Fine! There will be five  $NO_2$  left, no water, produces four  $HNO_3$  and two  $NO$ 's (presses enter) Got it wrong ... Oh only five waters react ... got it.

**Student 6:** I'll do the next one ... molecules of  $C_2H_6$  are two ... oxygen zero ...  $CO_2$  ... 12 and water ... 18 (presses enter) NO .. where? ... How? ... OK ... got it, let's move on.

*Figure 7-13 Interaction sequence B with Dyad 6 (within the Interpreting Equations module)*

**Student 6:** Pretty good eh?

**Student 7:** Yeah ... I like it.

**Student 6:** How can two colourless liquids make a yellow liquid?

**Student 7:** Why not?

**Student 6:** Well ... if you mix water and vinegar they remain colourless, but water and cordial remains the colour of cordial.

**Student 7:** But all of those thing already have water in them ... so there's no difference ... chemicals can give off any colour that they want ... many solids don't give off any colour at all ... like salt in water ... you can't see it ... it doesn't give off colour but its there.

**Student 6:** Rubbish ... you can't see it because it's dissolved.

**Student 7:** If you can't see it then how can you tell ... different chemical decide whether they give off colour and what colour they give off.

**Student 6:** Are you sure?

**Student 7:** Course I am ... lead and iodide were both colourless before but put them together and they turn yellow ... what about those magic pens ... they are blue inside but if you take them into the sun, they are red or something.

*Figure 7-14 Interaction sequence C with Dyad 6 (within the Molecular Equations module)*

Figure 7-12, illustrates interaction sequence A between the students in Dyad 6. In this sequence, the students appear to be friendly and supportive of each other. It also indicates that Student 7 was quite prepared to let his partner make the decisions relating to navigation of the computer through the IMM software and let him utilise and control the computer. These students showed some evidence of discussions relating to the exercises under study, with both students participating reasonably well, although Student 7 had fewer incidences of participation than his partner.

In Figure 7-13, the interactions indicate that while both students participated, Student 7 was more reluctant and required prompting from his partner. It also indicates that much of the discussion between the two students was expository and procedural in nature. These students did not take advantage of the many discrepant events or respond to the feedback provided by the IMM software for further discussion and tended to accept that they had mistake and continued on with the program, without investigating or discussing the reasons for their errors.

In Figure 7-14, Student 6 wants to understand how two colourless liquids could possibly be mixed and the resulting mixture produce a bright yellow colour. His partner, who felt that such an observation was simple and attempted to explain it. The dialogue indicated that Student 7 had a very simple and inaccurate understanding of the chemistry involved and attempted to personalise the particles and refer to them as being able to emit any colour that they want. The interaction highlighted several weaknesses or inadequacies in these students' knowledge, but did indicate that the students through discussion came to a similar conclusion, which was unfortunately, an unscientific explanation.

### **Peer Conflict and Co-construction of Knowledge**

The collaborative sequences of interactions were analysed and categorised as either co-constructions or conflicts. The conflicts were examined to find out whether they led to a divergence or convergence of understanding and how they resolved the conflict. The number of peer conflicts for each dyad is summarised in Table 7-2 and discussed below.

These data indicate that the scaffolded dyads had a total of 14 conflicts, four of which resulted from interaction with the Molecular Equation module and 10 from interaction with the Interpreting Equation module. In contrast, the non-scaffolded dyads had a total of 20 peer conflicts, which were evenly distributed between the two modules. An analysis of these conflicts indicates that fewer conflicts were evident in the scaffolded dyads when they were using the IMM module in which they utilised the worksheets. In contrast, they had an equal number of peer conflicts as the non-scaffolded dyads in the Interpreting Equation module, in which no scaffolded worksheet was provided. An examination of the interactions between dyads whilst working on the Molecular Equation module indicates that those dyads using the scaffolded worksheets, used the guides to direct their investigation of the exercise under study. In comparison, the remaining dyads did not have any additional tools to structure their learning and as such were guided only by their own cognition.

Table 7-2  
*Instances of peer conflict*

	Dyads	Module 1 Molecular Equations	Module 3 Interpreting Equations	Total number of conflicts
Scaffolded dyads	1	1	4	5
	2	2	4	6
	3	1	2	3
	Total	4	10	14
Non- scaffolded dyads	4	1	2	3
	5	4	5	9
	6	5	3	8
	Total	10	10	20

The conflicts in dyad interactions were classified according to whether they led to a divergence or a convergence of opinion or understanding prior to feedback by the IMM software. The results indicate that within the scaffolded dyads, 93% of all conflicts resulted in the convergence, compared to only 37% of the non-scaffolded dyads. Given the increased degree of mutuality in these scaffolded dyads, as shown in Table 7-1, this is not a surprising result. This suggests that students in a dyad formed similar opinions and conclusions as a result of the increased collaboration within the dyad.

Table 7-3

*Conflicts: divergence or convergence.*

	Dyads	Convergence	Divergence	Total number of conflicts
Scaffolded dyads	1	5	0	5
	2	6	0	6
	3	2	1	3
	Total	13	1	14
Non-scaffolded dyads	4	1	2	3
	5	4	5	9
	6	2	5	8 <sup>a</sup>
	Total	7	12	19

Note: <sup>a</sup> indicates that it was not possible to ascertain whether one of the conflicts resulted in convergence or divergence.

Finally, the interactions of the students were classified as social, procedural, expository or cognitive as per the work of Oliver, Omari and Herrington (1998). These terms were identified and classified by these researchers as follows:

- **Social:** interactions in which students were discussing elements of a social nature and not directly associated with the lesson;
- **Procedural:** interactions in which students were discussing matters relating to the procedures and steps associated with the learning materials and the IMM environment;

- **Expository:** interactions in which facts and knowledge are exchanged between learners with little or no elaboration or development through the discussion;
- **Cognitive:** interactions in which students demonstrate critical thinking and reflection. Students' discussion leads to a gain in knowledge.

The analysis of these interactions are shown in Table 7-3.

Table 7-4  
*The nature of the interactions between dyads.*

	Dyads	Nature of interactions			
		Social	Procedural	Expository	Cognitive
<b>Scaffolded Dyads</b>	1	0	50	15	20
	2	1	55	8	34
	3	1	44	9	30
	<b>Total</b>	<b>2</b>	<b>149</b>	<b>32</b>	<b>54</b>
<b>Non-scaffolded Dyads</b>	4	10	8	26	8
	5	14	6	28	8
	6	12	9	15	14
	<b>Total</b>	<b>36</b>	<b>23</b>	<b>69</b>	<b>30</b>



These data indicate that the scaffolded dyads had substantially less social interaction than the non-scaffolded dyad. Such social interaction, in some instances appeared to result from a lack of motivation on the part of the dyad to work on the assigned tasks, a function of them going off-task or from a lack of direction. This is illustrated in the following excerpts from dyad interactions.

<b>Student 10:</b>	It's your turn now.
<b>Student 12:</b>	No ... you can go again.
<b>Student 10:</b>	I've done the last three and ...
<b>Student 12:</b>	What time is it?
<b>Student 10:</b>	Why? We just started.
<b>Student 12:</b>	Do we have to come here tomorrow night? I am planning to go the movies tomorrow with [a girls name]. She wants to go see something with a lot of action ... have you seen any good films?
<b>Student 10:</b>	I saw a video called "The Mummy" it was really cool ... great special effects and the girl in it is really hot!

*Figure 7-15 A social interaction between Students 10 and 12*

<b>Student 6:</b>	This stuff isn't so hard.
<b>Student 7:</b>	Rubbish ... this is hard ... I can't seem to get it right. I don't get it ... what's the point.
<b>Student 6:</b>	Why did you do this then?
<b>Student 7:</b>	I thought it might help me ... I'm just dumb.
<b>Student 6:</b>	I'll help you.
<b>Student 7:</b>	Don't worry about it ... I'm not doing chem next year ... there's no way I'm doing this again.

*Figure 7-16 A social interaction between Students 6 and 7 in which Student 7 exhibits low self-esteem and a lack of motivation.*

The scaffolded dyads interacted more on procedural matters than the non-scaffolded dyads. These interactions tended to involve a member of a particular dyad reading the various guides on the scaffolded worksheets to his partner in order to direct the learning activity. This did not occur with the non-scaffolded dyads, with procedural interactions

tending to be focussed on the navigation through the IMM software. These interactions are illustrated in the following sequence.

<b>Student 5:</b>	What do we look for now?
<b>Student 1:</b>	Hang on ... we have to watch the video again and this time get the colours of the reactants. That means get the colour of iron and chlorine.
<b>Student 5:</b>	No worries (presses play) ... iron is dark grey and chlorine is greenish-yellow ... now what?
<b>Student 1:</b>	We have to record the colour of the product ... I think it was dark brown.
<b>Student 5:</b>	OK ... point 5 ... watch the computer simulation (plays simulation). Now replay the simulation and note the following ...

*Figure 7-17 An interaction between Students 1 and 5 discussing the procedure to be followed.*

<b>Student 8:</b>	What should we look at first ... the simulation, the equation or the demonstration?
<b>Student 9:</b>	Does it matter?
<b>Student 8:</b>	Probably not ... let me ask him ... Mr Grimes what part do we do first.
<b>Researcher:</b>	You can use any part of the IMM software that you would like to use ... remember that your goal is to try to better understand matter and how to balance equations.
<b>Student 8:</b>	So it doesn't matter?
<b>Researcher:</b>	No ... there are many ways that you can do it. Do what is best for your pair?
<b>Student 8:</b>	What do you want to look at first?

*Figure 7-18 An interaction between Students 8 and 9 discussing the procedure to be followed.*

Finally, of the remaining interactions: expository and cognitive, it was found that those dyads that were previously classified as having a high level of mutuality of engagement had a greater number of cognitive interactions than expository, whereas those

that were classified as low in mutuality, had a lower number of cognitive interactions compared to the number of expository interactions. Given the previous analysis of these interactions, in terms of this mode of collaboration, the resulting number of expository and cognitive interactions for each dyad was not surprising and supported previous findings.

### **Discussion, Assertions and Observations**

The term collaborative learning was defined by Slavin (1995) as referring to "any broad range of teaching strategies that share the provision of opportunities for students to work together in small, face-to-face groups" (p. 1). In this paper, Slavin states that collaborative learning has long been a tradition in formal European education and notes that Comenius (17<sup>th</sup> century) described a system of such learning stating that "very true is the phrase, *he who teaches others, educates himself*, not only because he consolidates the knowledge by repetition, but because he finds opportunities to advance deeper into things" (in *Didactica Magna*; cited by Huber, 1992).

This belief in collaborative learning was further enhanced by the developmental theories of Piaget and Vygotsky, which have emphasised the importance of discussion and joint problem solving. This was further developed by Vygotsky (1978) and Wood, Bruner and Ross (1976) to include scaffolded instruction, in which both the teacher and the learner share the responsibility for the learning process.

The diverse range of collaborative techniques and strategies arises from its basis in two principles: one social and the other cognitive in emphasis, as described by Light and Mevarech (1992). In this paper, these authors cite research from Johnson, Johnson and Maruyama (1983), who claim that educational sociologists assume that learning under "positive contract conditions" can have positive effects on students' motivation, self-esteem and academic learning. Light and Mevarech (1992) also state that cognitive psychologists contend that cognitive interactions such as conflict resolution, cognitive scaffolding with no apparent conflict, reciprocal peer tutoring, execution of cognitive and metacognitive processes and modelling can all have a positive effect on cognitive development. These authors however, state that the effects of such collaborative techniques in the cognitive

domain are not as clear as those in the social-affective domain. They cite the work of Nastasi and Clements (1991) who claim that recent reviews of collaborative learning techniques although generally resulting in improvement in academic achievement, find that problem-solving skills and creativity are quite variable in achievement.

With the advances in technology and the development of IMM software, researchers and practitioners are now beginning to investigate the use of a previously considered tool for individualised instruction Computer Assisted Learning (CAL) within a collaborative environment. The main questions that need to be addressed in this area are whether the IMM environment can contribute to collaborative learning; are the interactions of the users promoted or enhanced, within a collaborative framework, by IMM software; how can the IMM environment be structured or utilised to promote learning within a collaborative setting.

Data presented in this chapter suggest that students in the scaffolded dyads worked more collaboratively than those in the non-scaffolded dyads. This was confirmed by examining student interactions in terms of the three modes of collaboration as utilised by Tao and Gunstone (1997); joint on-task engagement, equality of engagement and mutuality of engagement. In a study by Looi and Tan (1998), researchers concluded that expert scaffolding provided by a computer-based learning environment promoted discussion between learners. Although such interaction was not the prime focus of their research, they concluded that such scaffolding, although originally designed for individualised learning may promote interaction and academic achievement within the Cognitive-Apprenticeship Model.

These data suggest that scaffolded instruction results in a higher level of joint on-task engagement, a higher equality of engagement and in general, a greater mutuality of engagement. These assertions can be understood in that the scaffolded worksheet provided students with a set number of assigned tasks per worksheets that were often used by students, as a means of determining when they should alternate using the computer, which promoted a more equitable and collaborative environment. This statement is supported by

the results presented in Chapter 6, in which scaffolded dyads were observed to have a more equitable share in the ownership of instructional control. Further, these worksheets provided a basis and framework for students to discuss exercises, which had been dissected into a series of mini-tasks. This framework supported student discussion from procedural to cognitive interactions, which led to a greater equity of engagement between students and a more in-depth, connected level of discourse.

The evidence from this study permits the following assertions (7.1 - 7.3) to be made.

*Assertion 7.1*

*Scaffolded instruction results in a higher level of joint on-task engagement than that resulted from non-scaffolded instruction within the IMM environment.*

*Assertion 7.2*

*Scaffolded instruction results in a higher equality of engagement than non-scaffolded instruction within the IMM environment.*

*Assertion 7.3*

*In general, scaffolded instruction results in a greater mutuality of engagement than non-scaffolded instruction in an IMM environment.*

Although collaborative learning has been shown to result in improved academic achievement, Nastasi and Clements (1991) have noted that such improvements are variable in their extent. In this research, these data indicate that while the scaffolded dyads did work

more collaboratively, when compared on all three characteristics of collaboration, they did not achieve enhanced academic achievement when compared to the non-scaffolded dyads. These levels of achievement have been outlined in Chapters 4 and 5. In a similar vein, these data therefore suggest that enhanced levels of collaboration within a dyad do not necessarily result in increased levels of cognitive achievement. These findings support the work of Tao and Gunstone (1997), who investigated the interactions and academic achievement of a Year 10 science class whilst using a computer simulation designed to provide cognitive conflict that facilitated conceptual change. In this study the researchers, found that collaboration alone was not necessary for conceptual change.

The various characteristics of collaboration provide a means for discourse that can produce peer conflicts and the co-construction of knowledge, both of which can promote and facilitate conceptual change. However, the fact that similar levels of conceptual change and academic achievement can be gained through lower levels of collaboration suggest that collaboration alone is not sufficient for such improved cognitive development. This supports Assertion 7.4.

*Assertion 7.4*

*High levels of joint on-task engagement, equality of engagement and mutuality of engagement did not necessarily produce high levels of cognitive achievement.*

Within the domains of developmental psychology (in the extreme), it is argued that 'meaningful' conceptual change is self-directed. At the other end of the continuum, cognitive developmental theorists argue that conceptual change is the result of internalising cognitive activities originally experienced in the company of others (Brown & Palincsar, 1989). Other researchers, such as Brown and Reeve (1987) and Gelman and Brown (1985) support an interaction of these two extremes as the means by which meaningful conceptual change can take place. These researchers contend that a key feature in such conceptual

change is the internalisation of some event that was witnessed in a social setting that is then structured into the individual's cognition.

The epistemological basis of constructivism is that individuals construct their own understandings or knowledge through the interaction of what they already know and believe, and events and activities with which they come in contact (Cannella & Reiff, 1994; Richardson, 1997). This suggests that the interactions that occur between learners also has an impact on the learners' construction of an event. This notion has been well developed by the social constructivists, including Solomon, who have emphasised the importance of the social factors associated with the learning process, including, but not limited to the learners' interactions, desire for consensus and peer approval (Solomon, 1987).

Many researchers have identified and described the various interactions that occur within group learning environments (Piaget, 1967; Solomon, 1987; Linn & Burbules, 1993). Such research has identified that learners can construct knowledge together through agreement (co-construction) or through peer conflict, which has the potential to result in either a divergence or convergence of knowledge upon conflict resolution.

In this research, it was found that all dyads experienced conflicts, some of which resulted in a divergence of ideas and thinking and others that resulted in a convergence. In addition, some peer conflicts, although generating further discussion, did not always result in conceptual change. However, regardless of the outcome of the conflict, the dyad in each case received feedback and correct responses from the IMM software. Such feedback, in some situations perpetuated further discussion and in others resulted in social acceptance of the answer. These interactions and feedback did not always result in conceptual change. This also suggests that conceptual change, as previously discussed requires a critical personal reflection or review of the provided information, followed by the internalisation of the concept under study, as noted by Gelman and Brown (1985).

These data also indicate that both scaffolded and non-scaffolded dyads experienced a similar number of conflicts in the Interpreting Equations module, which was not

scaffolded by the worksheets, yet of the dyads using the worksheets, 60% experienced less conflicts in the Molecular Equations module than the non-scaffolded dyads. This data may be explained by the fact that the scaffolded worksheets were only supplied for the Molecular Equation module and that both groups had to work through the Interpreting Equations module without scaffolding. These data may also suggest that the particular scaffolding supplied to students either limited discussion, therefore minimising peer conflicts or provided a structure that assisted students to co-construct knowledge with fewer conflicts. Given that the scaffolded dyads tended to have a greater mutuality of engagement and were assessed to have participated in a greater number of cognitive interactions, as defined by Oliver, Omari and Herrington (1998), the data suggests that the scaffolds did not limit discussion. This suggests that the scaffolding supplied may have assisted students to co-construct knowledge.

In addition, as seen in the various interview excerpts (Figure 7-2 and Figure 7-14) some of the interactions between learners (both co-construction and peer conflict) did not result in scientifically accurate constructs. This phenomenon has been discussed in some detail by Solomon (1993) and has been attributed to the concept of 'two -worlds of knowledge' and the lack of scientific reasoning skills or logic.

The evidence from this study permits the following assertions (7.5 - 7.7) to be made.

*Assertion 7.5*

*Peer conflicts that develop either divergence or convergence of thinking do not always result in conceptual change.*



**Assertion 7.6**

*The use of scaffolded worksheets reduced the number of peer conflicts evident in learners' interactions and promoted the co-construction of knowledge.*

**Assertion 7.7**

*The interaction of learners in a collaborative group-learning environment does not always result in conceptual change consistent with scientific concepts.*

Many researchers have strongly advocated the use of group learning; in that students learning together co-construct more powerful understandings than they could construct alone (Dockterman, 1990). However, others such as Linn and Burbules (1993) contend that this is far too simplistic a notion. These researchers claim that the important issues in the success of group learning activities are the social structure of the group, the goals of the individuals in the group, the nature and process of knowledge construction and the nature of the learning task.

By comparing the three characteristics of collaboration reported earlier, the perceived variance in student motivation and the equality of the interactions with the IMM software between dyads, these data have established that the level of collaboration varied between dyads in this study. Further, it can be seen that the level of collaboration was greater in the scaffolded dyads than in the non-scaffolded dyads. Since such collaboration has been related to social interaction (Linn & Burbules, 1993), it seems appropriate that the level of collaboration may be affected by the social structure or nature of the group.

The evidence from this study permits the following assertion (7.8) to be made.

**Assertion 7.8**

***The level of collaboration varied between dyads and were influenced by dyad composition, and student motivation.***

The many interactions that occurred between the various dyads during the study were analysed in terms of the four basic classifications, as previously identified by Oliver, Omari and Herrington (1998). These interactions included social, procedural, expository and cognitive. The results presented in this Chapter indicate that the scaffolded dyads had fewer social interactions than the non-scaffolded dyads. The higher levels of procedural and cognitive interactions of the scaffolded dyads, suggest that they were more focussed on the task at hand and had a higher on-task engagement compared to the non-scaffolded dyads. Upon analysis of their various interactions, it can be seen that the cognitive interactions of the scaffolded dyads were greater in number than the non-scaffolded dyads and were centred around the scaffolded guides. In comparison, the cognitive interactions produced by the non-scaffolded dyads appeared to be unstructured in their order and direction. This suggests that the scaffolded worksheets provided a guide not only for students to use the IMM software, but to initiate and organise discussions.

The evidence from this study permits the following assertions and observations (7.9 - 7.14) to be made.

**Assertion 7.9**

***The scaffolded worksheets appeared to focus student attention to particular relevant aspects of the IMM software at appropriate times and support the learning process.***

**Assertion 7.10**

*The scaffolded worksheet provided a basis and guide for student discussions.*

**Observation 7.11**

*Student dyads that utilised the scaffolded worksheets had a lower number of social interactions than in the non-scaffolded dyads.*

**Observation 7.12**

*Student dyads that utilised the scaffolded worksheets had a greater number of total interactions than those in the non-scaffolded dyads as a result of the much greater number of procedural interactions arising from following the guides in the scaffolded worksheets.*

**Observation 7.13**

*Students in the scaffolded dyads tended to have more in-depth discussions about the exercise under study compared to those students in the non-scaffolded dyads.*

**Observation 7.14**

*Students in the non-scaffolded dyads tended to state their ideas and opinions during interactions within the dyad as opposed to open discussion and the generation of supportive arguments.*

Additionally, the students that utilised the scaffolded worksheets generated detailed notes on the particulate nature of matter and on the process of balancing and interpreting chemical equations that were not produced by the non-scaffolded dyads.

The evidence from this study permits the following assertion (7.15) to be made.

**Assertion 7.15**

*The use of the scaffolded worksheets encouraged students to develop personal summary notes of the exercises undertaken.*

### Chapter Summary

The assertions and observations developed through this chapter are summarised below:

- 7.1 *Scaffolded instruction results in a higher level of joint on-task engagement than that resulted from non-scaffolded instruction within the IMM environment.*
- 7.2 *Scaffolded instruction results in a higher equality of engagement than non-scaffolded instruction within the IMM environment.*
- 7.3 *In general, scaffolded instruction results in a greater mutuality of engagement than non-scaffolded instruction in an IMM environment.*
- 7.4 *High levels of joint on-task engagement, equality of engagement and mutuality of engagement did not necessarily produce high levels of cognitive achievement.*
- 7.5 *Peer conflicts that develop either divergence or convergence of thinking do not always result in conceptual change.*

- 7.6 *The use of scaffolded worksheets reduced the number of peer conflicts evident in learners' interactions and promoted the co-construction of knowledge.*
- 7.7 *The interaction of learners in a collaborative group-learning environment does not always result in conceptual change consistent with scientific concepts.*
- 7.8 *The level of collaboration varied between dyads and were influenced by dyad composition, and student motivation.*
- 7.9 *The scaffolded worksheets appeared to focus student attention to particular relevant aspects of the IMM software at appropriate times and support the learning process.*
- 7.10 *The scaffolded worksheet provided a basis and guide for student discussions.*
- 7.11 *Student dyads that utilised the scaffolded worksheets had a lower number of social interactions than in the non-scaffolded dyads.*
- 7.12 *Student dyads that utilised the scaffolded worksheets had a greater number of total interactions than those in the non-scaffolded dyads as a result of the much greater number of procedural interactions arising from following the guides in the scaffolded worksheets.*
- 7.13 *Students in the scaffolded dyads tended to have more in-depth discussions about the exercise under study compared to those students in the non-scaffolded dyads.*
- 7.14 *Students in the non-scaffolded dyads tended to state their ideas and opinions during interactions within the dyad as opposed to open discussion and the generation of supportive arguments.*
- 7.15 *The use of the scaffolded worksheets encouraged students to develop personal summary notes of the exercises undertaken.*

## **CHAPTER 8**

### **GENERAL DISCUSSIONS AND CONCLUSIONS**

This Chapter presents a general discussion of the research findings. The assertions made in Chapters 4, 5, 6 and 7 are considered within the framework of the original research questions and some general assertions and conclusions are drawn and discussed. The development of the general assertions from the assertions developed in Chapters 4, 5, 6 and 7 is illustrated in Appendix 4.

The research questions under investigation were:

1. How does scaffolding affect the way in which students interact with the interactive multimedia software?
2. How does scaffolding affect the way in which students interact and collaborate with each other whilst working on the interactive multimedia software?
3. Is there any evidence of enhanced understanding of the particulate nature of chemical reactions and success in writing and balancing chemical equations following use of this program with scaffolding?

The discussion and development of general assertions considers conceptual growth and learning, interactions between students and the IMM software and the nature of interactions between students.

## Conceptual Growth and Learning

Through the use of the IMM software, *Balancing and Interpreting Chemical Equations* (Garnett et al. 1997a) students developed new chemical knowledge concerning the particulate nature of matter. These students were able to see that some groups of atoms were joined together, and that the spoken commentary in the simulation, explained that they were called molecules and that these molecules were represented by specific formulas. While the ability to understand the significance of such representations in the IMM software took some students longer than others, it may be that the development and ability to understand this abstract phenomenon requires students to consider the concept from a variety of sub-concepts. These sub-concepts link together to provide suitable evidence to develop an understanding of the particulate nature of matter. From this standpoint, the viewing of a group of atoms joined together provides a concrete image of the concept, whereas the commentary introduces and utilises the term 'molecule' and then indicates how such a molecule can be represented symbolically. This series of sub-concepts appear to provide a framework for the student to not only accept new knowledge, but also to understand, learn and provide a means for information retrieval.

The development of this learning framework is well supported by the Information Processing Model, the Generative Learning Model and the ideas of constructivism, in which students received information via their senses and then processed the information as a variety of memory structures. The advantage of IMM in this context is the provision of information in a variety of modes including text, audio and imagery, which facilitates multiple encoding and the development of rich memory structures. This ability to receive new information in a number of different forms was considered by Bagui (1998) to be the main reason for the success of multimedia platforms in such instruction because of the "...parallels between multimedia and the 'natural' way people learn, as explained by the information processing theory" (p. 4). Bagui (1998) considered that multiple encoding strengthened the validity of the construct and assisted in memory retention and information retrieval.

The majority of students in this study demonstrated an enhanced understanding of and an ability to correctly use, a variety of chemical concepts, including atom, molecule and compound; an enhanced ability to represent and describe these structures at the various levels of representation, which resulted in significant changes to the manner in which students viewed, considered and interpreted chemical equations after interaction with the IMM software. Further, their representations of such concepts were more detailed in nature following such interaction, with many students beginning to consider more advanced concepts, including the relative sizes of the various atoms involved in a specific representation. These advanced concepts would have been developed through interaction with the animated simulations and illustrates the importance of such concrete images for the understanding of such abstract concepts. This enhanced understanding of the particulate nature of matter supports the development of General Assertions 1, 2 and 3.

Appendix 4 maps the synthesis of these general assertions from the assertions generated in the results chapters.

**General Assertion 1**

Students developed new chemical knowledge concerning the particulate nature of matter through interaction with the IMM software.

**General Assertion 2**

Student interaction with the IMM software resulted in important changes to the manner in which students viewed, considered and interpreted chemical equations.



### **General Assertion 3**

**Interaction with the IMM software helped students develop a framework for considering the process of balancing and interpreting chemical equations from the macroscopic, particulate and symbolic levels of representation.**

One of the issues confronting learners in any environment is their ability and willingness to attend to the information and opportunities provided by the learning experience. This ability may be affected by a variety of personal, social and biological factors confronting or impacting on the learner. For many students, the IMM environment appears to be more stimulating and interesting than the more traditional forums of academic learning. This in itself may provide motivational structures that support or enhance the learning environment. Similarly, it appears that a lack of perceived competence by the learner or interest in this platform may affect some students' willingness or ability to attend to the various sensory information provided by the IMM software, which would limit their opportunities to explore new concepts. This was evident in some of the interactions between learners, in which one student had limited experience with IMM software in comparison to the other learner in the dyad. This difference in experience between learners appears to result in differential instructional control of the IMM software. When one of the learners is allowed to dominate in the interaction with the IMM software, the other student's opportunities for learning are reduced. This lack of equity in instructional control appears to be related to a number of personal and social factors within the dyad.

In addition to the above, it appears reasonable that many of the factors influencing students to remain focused and motivated to learn in a more traditional environment would also affect the learning and interaction with the IMM software.

Another issue affecting the ability of students to learn in any environment is their ability to consider new information in light of prior knowledge and experience. In this study, it was illustrated that a student's existing conception of a 'product' played a role in the learning about the limiting reagent concept. For some students the ability to understand such concepts as limiting reagents was not a simple addition of new knowledge, but rather required a new definition of the term 'product' and a reorganization of a previously accepted and learned schema (Biggs & Moore, 1993). This illustrates the importance of the overall conceptual ecology in learning particular constructs and the need to provide a variety of sensory cues for students to work through these issues (Bagui, 1998). Analysis of dialogue between members of dyads also revealed the role played by IMM feedback that confronted students creating disequilibrium. The need to resolve the disequilibrium appeared to provide motivation for working out a better understanding and accommodating their conception. The impact of these variables on the learning process supports the generation of General Assertion 4.

**General Assertion 4:**

The students' prior knowledge, attitude to learning in an IMM environment, attitudes and motivation to learn, ability to work effectively within the constraints of the collaborative learning environment and their facility with language play a key role in their own learning.

The use of the scaffolded guides provided an opportunity for students to consider various aspects of the sensory information provided by the IMM software at particular, relevant times in the learning process. These served as a means by which students could receive metacognitive training of the various cues to attend to at a particular point in the learning process. The use of scaffolded guides in the IMM learning environment served to focus student attention to the salient features of the IMM software at appropriate times in

the learning process. This function served to encourage students to attend to, and process small amounts of sensory information at any one time, thereby reducing the load on working memory (Atkinson & Shiffrin, 1968; Biggs & Moore, 1993). In addition, the scaffolded guides were designed to encourage students to process information through multiple encoding in order to strengthen the validity of the constructs and assist in memory retention and information retrieval.

The use of guides with differing levels of scaffolding permitted students the opportunity to decrease the amount of support that they required to complete a task and understand the concepts presented at an appropriate rate. Although the dyads using these scaffolds were, in general, keen to move from levels of higher to lower scaffolding, it appears that this willingness was affected by the dyads perception of their ability and their confidence to approach the learning process with decreased support. Although dyads using the scaffolded guides tended to move from worksheets with higher to lower levels of support with increased experience and confidence, they accessed the instructional modules in the IMM software at a greater frequency than that required by the scaffolded guide being utilised. Not surprisingly, these scaffolded dyads accessed the instructional modules in the sequence prescribed by the scaffolded guides: demonstration (macroscopic), simulation (particulate) and then the equation (symbolic). This order in which the instructional modules were accessed was not evident in the non-scaffolded dyads and indeed these dyads did not access every instructional module available for each reaction.

Given that such effective use of the instructional modules was observed in the scaffolded dyads' user history and not in that of the non-scaffolded dyads, this suggests that the use of the scaffolded guides developed an appreciation by students, at a metacognitive level, of the importance of considering chemical reactions from a macroscopic, particulate and then to a symbolic level of representation.

The scaffolded guides provided structured statements, instructions and questions that assisted students to maintain focus during task completion and a framework for students to discuss relevant issues. Discussion within scaffolded dyads was greater in mutuality and equity compared to the non-scaffolded dyads. Although discussions did not always result in higher levels of cognitive achievement, these discussions did provide students with the opportunity to begin to verbalise and test the constructs and the relationships generated by them between a variety of concepts. This ability to verbalise and test their tentative conceptualisations, provides an additional opportunity within the learning environment for students, which may have the potential to result in greater levels of cognitive achievement or as a means of reinforcing the personal schema developed and constructed by the learner. The impact of these variables on the learning process supports the generation of General Assertions 5 and 6.

**General Assertion 5**

The use of scaffolded guides developed an appreciation, at a metacognitive level of the importance of considering chemical reactions from the macroscopic, particulate and then the symbolic levels of representation.

**General Assertion 6**

The use of scaffolded guides provided a tool that enhanced and facilitated higher levels of on-task engagement and a greater equality and mutuality of engagement, although not always leading to higher levels of cognitive achievement, did enhance the IMM learning environment and the opportunity for conceptual change.

### **Interactions Between Students and the IMM Software**

The scaffolds provided cues for students to attend to particular sensory information at relevant times in the learning process. The means by which these guides achieved this attention to sensory cues was through various structured statements, instructions and questions. These written directions required students to utilise the instructional modules in a particular sequence, from the macroscopic to the particulate and finally to the symbolic. This sequence was selected to provide a gradual increase in the level of abstraction and to attempt to provide a real life episode, which could be considered at increasing challenging levels of representation, which could be related to the context provided by the prior experience.

In addition to viewing the instructional paths in a predetermined sequence, students using scaffolds were also required to view the instructional paths multiple times, with the frequency of repetition dependent upon the level of scaffolding utilised. In contrast, students in the non-scaffolded dyads self-determined the instructional paths accessed and their frequency of access.

The purpose in encouraging students to focus on particular instructional paths through multiple viewings was to enable them to focus on smaller units of sensory information. As previously discussed, the Demonstration and Simulation instructional paths contained a vast array of sensory information, in text, audio and visual forms. Repetitive viewing of these modules permits students the opportunity to focus on a particular aspect of sensory information. This enhances the student's ability to attend to, and process the relevant sensory information at the appropriate time in the learning sequence. It also provides an opportunity for students, through time and repeated viewings, to consider and process all available sensory information, which should enable multiple encoding and thus increase the validity of the constructs and assist in memory retention and information retrieval.

Students in the scaffolded groups were required to use the instructional paths more fully than the students with the scaffolded guides. However, as the level of scaffolding was decreased, it was noted that the frequency with which they viewed the various modules was greater than that required by the scaffolded instructions. This suggests that not only did they make more effective use of the instructional paths available to them than the non-scaffolded groups, but in addition, these students had developed an appreciation of the value of the various levels of representation within the IMM software in the process of balancing and interpreting chemical equations.

The scaffolded guides also provided a set sequence of instructions and statements that clearly defined the commencement and completion of a set task. This appeared to signal to these students an appropriate opportunity to swap learner control. Given that the student with the learner control was typically responsible for instructional control, it suggests that the use of the scaffolded guides provided an enhanced opportunity for the learning environment to be more equitable and to attend to the needs of both learners. These guides also provided a basis for a greater mutuality of interactions, as previously discussed, which provided the potential for an enhanced learning environment within the dyad.

Finally, it appears that the IMM software, whilst providing many opportunities to enhance learning, was not fully utilised by the students without the assistance of the scaffolded guides. As a result, the enhancing benefit and opportunities presented by IMM software in presenting information in a variety of forms, the provision of concrete images and the value of the various levels of representation were not realised by these students. These students did not appear to approach any of the required tasks in any consistent, systematic order. This suggests that the students did not have the metacognitive skills to maximise the opportunities and potential of this IMM software and that the software itself did not provide adequate scaffolding or metacognitive assistance to these students to direct and maximize this learning opportunity. The impact of these variables on the learning process supports the generation of General Assertions 7, 8, 9 and 10.

General Assertion 7

Students who used the scaffolded guides made more effective use of the instructional paths available within the IMM software to study the processes of balancing and interpreting chemical equations from a macroscopic, particulate and to symbolic level of representation.

General Assertion 8

The scaffolded guides signaled to students the completion of a set task and provided an opportunity for a swap of learner control and therefore created a more equitable learning opportunity for both members of the dyad.

General Assertion 9

The scaffolded guides enhanced student interaction with the IMM environment by encouraging students to repeatedly view and consider particular instructional paths and as such provided the opportunity for a more effective learning environment.

General Assertion 10

The IMM software alone did not provide sufficient scaffolding or metacognitive assistance for the students in this study.

### **Nature of Interactions Between Students**

The nature of collaborative interactions between learners in dyads working in an IMM environment created opportunities for learning. The use of scaffolded guides generated interactions between learners of greater mutuality and equality than those in dyads not using the scaffolds. These richer interactions in scaffolded dyads enabled a deeper exploration of ideas compared to the sparse interactions between students who did not use the scaffolded guides. These students in the non-scaffolded dyads tended to merely state their opinions and provided few opportunities for the individual or the dyad to further explore ideas or concepts. The freedom of discussion generated by the students in the scaffolded dyads provided a positive and rich environment in which, typically both students in the dyad appeared comfortable to share their ideas. This willingness to fully participate in these discussions produced an environment which enhanced the opportunity for both students in the dyad to maximize their learning opportunities.

The more positive learning environment developed by the dyads using the scaffolded guides also resulted in an increased level of collaboration between these students compared to others in the study. The level of collaboration between students in the non-scaffolded groups appeared to be more strongly influenced by both personal and social factors than in the scaffolded dyads.

Finally, the nature and extent of the interactions experienced within the scaffolded groups did not appear to deteriorate with changes to the level of scaffolding utilised. Students in these dyads appeared to maintain their level of interactions as the level of support structures and the subsequent number of instructions and or statements to be discussed decreased. This, together with the nature of their interactions with the software, throughout this process suggests that the students were working within an environment that was conducive to positive interactions and discussions concerning the learning task. The impact of these variables on the learning process supports the generation of General Assertions 11, 12 and 13.



**General Assertion 11**

**The use of scaffolded guides enhanced the positive learning interactions between students within the IMM environment.**

**General Assertion 12**

**The level of collaboration between students within dyads was influenced by the use/non-use of the scaffolded guides as well as other personal and social factors present within the dyad.**

**General Assertion 13**

**The fading of support structures within the guided worksheets did not result in a deterioration of the nature and extent of the interactions within the dyad.**

## **Conclusions**

The general assertions, developed from this research and the discussion presented above permit the following conclusions to be drawn from this study, which will be referenced to the research questions posed. The development of these conclusions from the general assertions is illustrated in Appendix 5.

1. How does scaffolding affect the way in which students interact with the interactive multimedia software?

### **Conclusion 1**

Scaffolding enhanced most students' interaction with the IMM software by more actively engaging the learners to relevant aspects of the content to be studied and by leading learners through that content in an appropriate sequence.

### **Conclusion 2**

Scaffolding created a more equitable learning environment for students working in dyads in an IMM environment by facilitating students taking turn in learner control.

2. How does scaffolding affect the way in which students interact and collaborate with each other whilst working on the interactive multimedia software?

**Conclusion 3**

Scaffolding enhanced the collaborative interactions between students working in dyads in an IMM environment by improving joint on-task engagement, equality and the mutuality of engagement.

3. Is there any evidence of enhanced understanding of the particulate nature of chemical reactions and success in writing and balancing chemical equations following use of this program with scaffolding?

**Conclusion 4**

Students working in scaffolded dyads developed a richer understanding of the particulate nature of matter, however, there is no indication that it enhanced success in writing or balancing chemical equations.

### **Conclusion 5:**

**Students using the scaffolding analysed the reactions in much greater detail, especially at the particulate level of representation and this resulted in more in-depth discussions between students, which may have resulted in an enhanced understanding of the nature of the chemical reaction.**

## **Implications**

### **Implications for Teaching**

After considering the research findings and the relevant literature, the following issues are raised as implications for the use of this IMM software within the classroom environment:

- **The program should be used with students over a number of consecutive lessons. Students should be directed to focus on one module at a time and encouraged to examine each reaction, provided in the modules, in great detail.**
- **Students should be provided with sufficient time within each lesson to reflect on and discuss the information provided by the IMM software. If students are given adequate time, then there is no need for them to rush through the perceived lesson content. Instead, they should be encouraged to work through examples thoroughly and in great detail, discussing relevant aspects of information provided. Only with adequate time, will students be able to attend to, process and then compare sensory information with**

existing knowledge and then have the opportunity to re-evaluate their understandings.

- **Teachers should develop appropriate printed scaffolded worksheets for their particular classes to accompany the use of this IMM software.** These scaffolded sheets should vary in their level of support and students should be encouraged to work through examples in the IMM software guided by worksheets of progressively lower support. These scaffolded worksheets could be maintained as electronic templates that students could access while working on the IMM software or alternatively as hard copies.
- **Teachers should discuss the IMM software with the students and detail the value of examining abstract phenomena from a macroscopic, particulate and then a symbolic level in order to develop an appreciation of the conceptual processes involved.** Students are more likely to follow instructions from teachers or those provided on worksheets if they understand the reason for the steps involved. While we cannot expect students to understand the complexities of the underlying pedagogical approach, they can be informed about the value in viewing particular abstract phenomena from a number of levels of representation.
- **Students should be paired in appropriate dyads to facilitate collaborative learning.** Teachers need to consider the dynamics of the students involved, gender-based issues (in the non-single sex classrooms), social factors and the skills, abilities and personal attributes of the individual learners. Indeed, the classroom environment and associated dynamics need to be supportive if collaborative learning is to be successful.
- **Students should be encouraged to discuss their thoughts and opinions (relating to the information provided by the IMM software) within the dyad.** In order to achieve such a discussion, teachers may need to do some

work prior to using the IMM software on the expectations and guidelines for collaborative group work and/or provide written questions that guide and promote discussion. Students should also be encouraged to respond to, and attempt to resolve disequilibrium in a positive manner and to have the confidence to seek teacher guidance for clarification. In order to achieve such dynamics, teachers need to work in a deliberate, planned and sustained manner on skills associated with group work, active listening and assist students to develop skills to resolve disequilibrium positively.

- **Students should be instructed to share the responsibility of mouse control.** The act of students taking turns in controlling the inputs to the computer and IMM software assist in developing both students in terms of their information technology skills, developing equity within the dyad and sharing the opportunity for instructional control.

### **Implications for Software Design**

After considering the research findings and the relevant literature, the following issues are raised as implications for the use of this IMM software within the classroom environment:

- **Software designers of complex IMM programs, intended for classroom use, should provide an initial instructional module that must be accessed prior to commencing work or viewing other components of the IMM application, that provides a suggested means of navigating within the program.**
- **Software designers could provide a level of inherent sequencing of instructional modules which students access, by preventing access to particular modules until prerequisite instructional paths have been accessed and completed successively.** In the example of the IMM software

*Balancing and Interpreting Chemical Equations* (Garnett et al. 1997a), designers could have blocked access to the Equation module and required students to view both the Demonstration and Simulation modules before the Equation module.

- **When designing software with complex graphics, particularly of abstract concepts, software designers could provide help/ information messages (callouts) that appear on screen when a computer pointer is placed over an object in the screen.** This may encourage students to spend some time exploring instructional modules and repeatedly viewing them in an attempt to extract all of the hidden messages on the screen. This technique would also provide students with the salient information in an additional form, which would support multiple encoding, as previously discussed.
- **Software designers should provide salient information in a variety of forms, including text, audio and visual.** This provision allows for the multiple encoding of salient information and assists the development of constructs, memory retention and information retrieval. Designers must however be careful not to provide unnecessary sensory information, that may distract student attention and result in an overload on working memory.
- **Software designers could provide a series of scaffolded questions within their IMM software to focus and direct student attention to the pertinent pieces of information at appropriate times in the learning sequence.** Given the capabilities of IMM, designers could prepare an item bank of appropriate guides from which students could choose. Designers could also incorporate program loops that repeat a section of the program, each time with a different focus. In the IMM software *Balancing and Interpreting Chemical Equations* (Garnett et al. 1997a), designers could direct students attention to one aspect of the simulation and then repeat the

simulation, this time drawing student attention to another salient feature and so on.

- **Designers need to develop computer screens that enhance student learning: by capturing the students' attention; helping the student find and organize pertinent information; and assist the student to integrate the information into the students' knowledge structure.** The design of computer screens needs to be colourful, such that students find the screen attractive, which then encourages student participation and use. However, designers must be careful not to provide non-essential sensory information that distracts from the salient features of the program or causes students' working memory to be overloaded.
- **Software designers should incorporate an internal structure into their IMM software that provides the salient features, controlled navigation and an internal structure that will still support the various dimensions of learning.** The design of IMM software needs to support the various dimensions in which individual learning occurs, while still providing all of the necessary information for the learning process. This must also be contained within an internal structure that supports controlled navigation through the software, in an attempt to provide the salient features at the appropriate sequence in the learning activity.



### **Implications for Further Research**

After considering the research findings and the relevant literature, the following issues are raised as implications for the use of this IMM software for future research:

- **The conceptual growth and development of students using this IMM software; their interactions with the IMM software; and the nature of the interactions between students working collaboratively in dyads should be examined in wider contexts.** A study is needed to examine the impact of this IMM software on a larger sample of students and now needs to include students from a variety of backgrounds, schools, abilities and gender, in order to provide a richer source of data, which may provide the ability for statistical generalisations to be made to a wider community of learners.
- **Does the use of this IMM software result in any other changes in the conceptual ecology, other than balancing and interpreting chemical equations?** Research is needed to establish whether use of this program has any affect on other conceptual aspects of chemistry, such as students' ability in problem solving, ability to perform calculations, or to consider various content specific areas in terms of various levels of representation.
- **Do all students attend to the specific forms of sensory information equally? What makes a particular form of sensory information more valid or important to a student than other forms?** Individuals learn through a variety of dimensions. Given the nature of the learning process, its dependency on prior experience, and the subsequent evaluation of those previously established constructs as the result of new experience, individuals need to attend to different forms of sensory information to varying degrees. Research is now needed to establish whether students respond to the various forms of sensory information, provided by IMM software differently. In addition, research is also needed to establish why some forms of sensory

information are more important to some individuals in the learning process than others.

- **Without scaffolding, what sensory information do students attend to primarily and why?** Without scaffolding some students simply view an instructional module once and then access the next and so on. In this process, what information do they attend to in the first instance, and why?
- **What factors affect the ability of individual students to work collaboratively in dyads in an IMM environment?** The collaborative learning environment appears to be a dynamic and supportive aspect of the learning process which encourages and stimulates discussion and debate. The dynamics of these settings must be better understood if teachers are to effectively utilize them in the classroom.

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## APPENDIX 1

### PROGRAM DESCRIPTION

The interactive multimedia software, *Balancing and Interpreting Chemical equations* (Garnett et al, 1997a) consists of three discrete IMM modules (Molecular Equations, Ionic Equations and Interpreting Equations) that are designed to introduce students to chemical reactions and develop skills in constructing and balancing equations, and the understandings necessary for their interpreting equations.

The program was developed as a result of research into student misconceptions in chemistry. It was designed to help students understand the particulate nature of matter, with respect to chemical reactions and to utilise this understanding, together with a macroscopic visualisation of chemical reactions to the understand, write and interpret the more abstract symbolic representation.

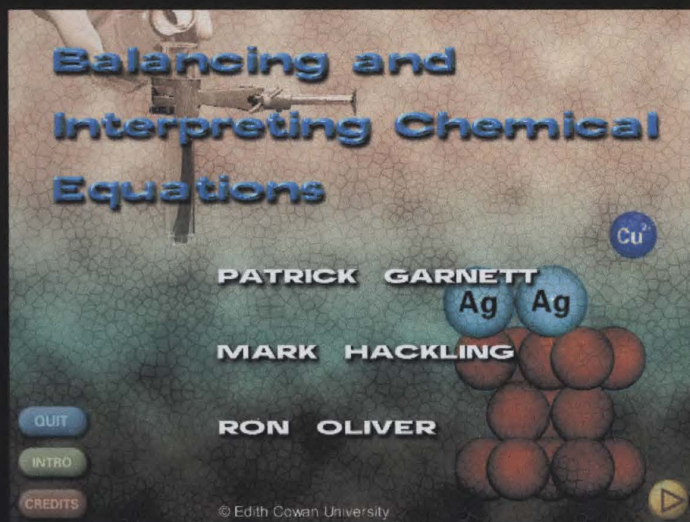


Figure 10-1 The title screen for the program *Balancing and Interpreting Chemical Equations*

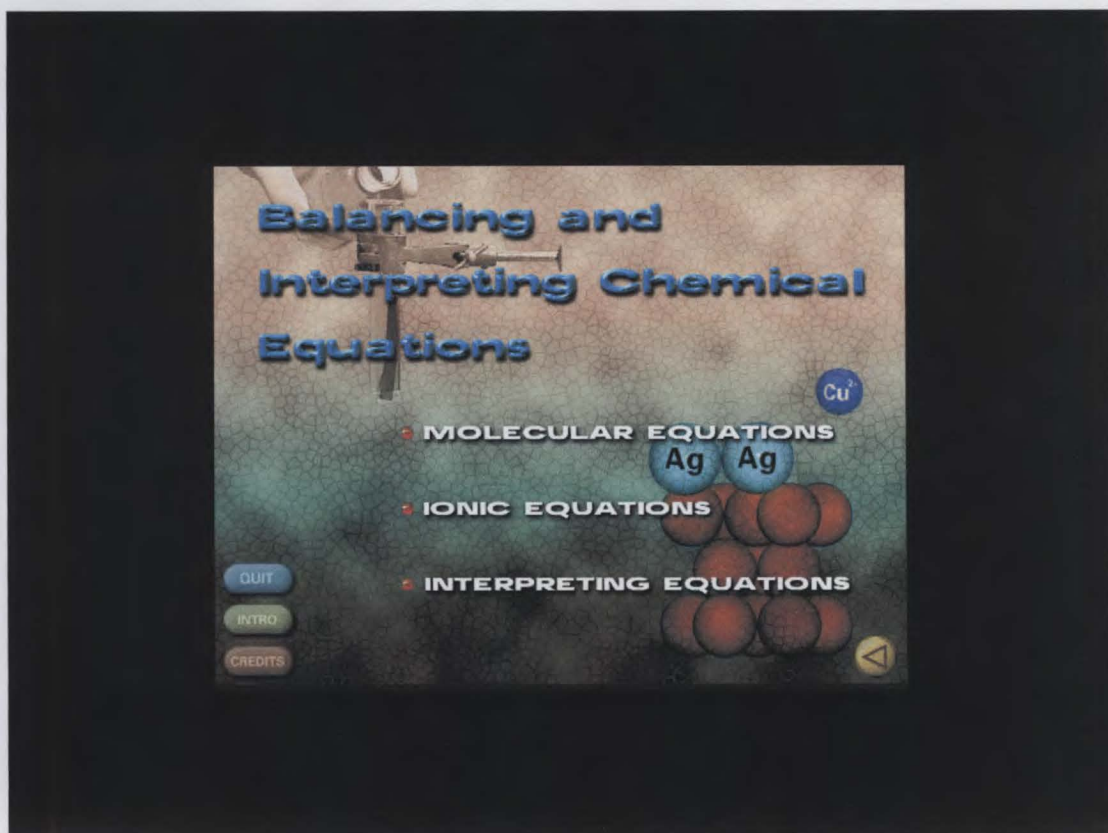


Figure 10-2 The computer page displaying the three available modules in the program *Balancing and Interpreting Chemical Equations*

**Module 1:** The first module provided information relating to eight molecular, chemical reactions. For each reaction, students were able to view and consider the reaction at three levels of representation, namely macroscopic, symbolic and the sub-microscopic or particulate level. Students were able to either view a video demonstration showing the actual reaction as it occurred, viewed a simulation at the particulate level and/or write a balanced chemical equation. These options are evident in the menu bar of Module 1, illustrated in Figure 10-3.



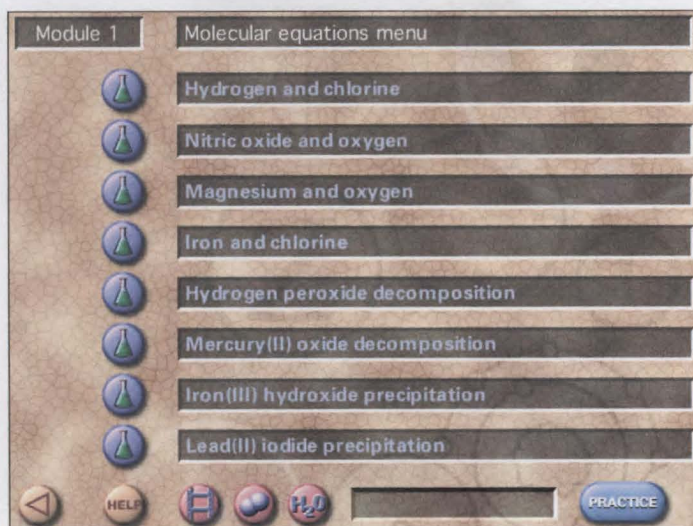


Figure 10-3 The menu of reaction available within the first module in the program *Balancing and Interpreting Chemical Equations*

The video segments in the IMM software package were short in duration, typically lasting about 20 seconds and showed a close-up view of the reaction and were accompanied by a verbal description of reactants, products and the progress of the reaction. An example of the screens displayed in this component of the model is shown in Figure 10-3.



*Figure 10-4 The computer screen at three different stages of a video clip.*

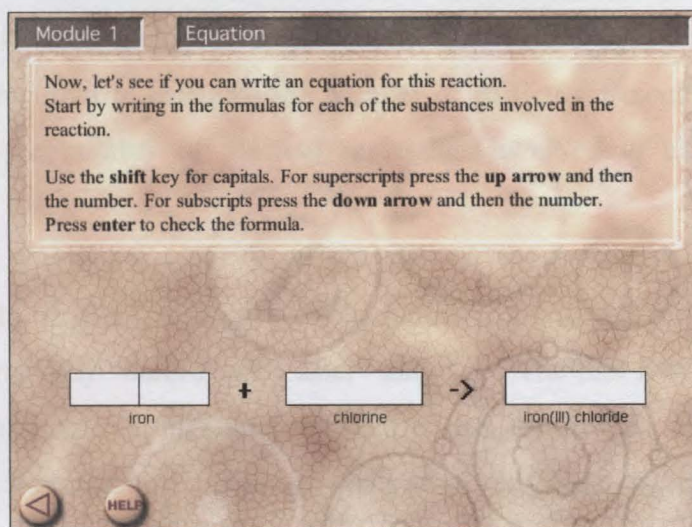
The animated simulations used dynamic computer generated graphics, which were of a similar duration to the video segments and were accompanied by a verbal description of what each coloured particle represented and how they interacted with one another. Some highlighted particles were also labelled with their symbol to aid identification. The simulation consisted of animated coloured spheres representing atoms and groups of spheres representing molecules. A regular array of spheres was used to represent solids. The spheres had translational motion but rotational and vibrational motions were not emphasised. An example of the screens displayed in this component of the model is shown in Figure 10-4.



*Figure 10-5 The computer screen at three different stages of animated simulation.*

The last level of representation, the balanced equation, was supported with a static particulate representation. Students were given suitable audio and visual feedback on their attempts to write and balance equations, to inform them of their progress and were provided with a practice set of 20 additional reactions to further develop their skills of writing balanced chemical equations. An example of the screens displayed in this component of the model is shown in Figure 10-5.





*Figure 10-6 The computer screen at three different stages of animated simulation.*

The third module consisted of seven parts in which students were challenged to develop their understanding of what chemical equations represented and to further enhance their skills in interpreting chemical equations.

In part 1 of the third module, students were required to interpret chemical equations by constructing molecular representations of the reactants and products represented by chemical equations based upon the coefficients in the equation. In part 3, students constructed molecular representations of the products formed in chemical reactions, from a given number of reactant molecules, which were simple multiples of the coefficients in the equations. In part 5, students constructed molecular representations of the products formed in chemical reactions, from a given number of reactant molecules present before a reaction.

In parts 2, 4 and 6 students completed simple calculations that were designed to develop an understanding of the meaning of the coefficients in the chemical equations. In part 2, these interpretations were based upon the coefficients in the equation; part 4, upon multiples of the coefficients in the equation; and in part 6 students were required to calculate the number of particles present after a chemical reaction from the number of reacting molecules involved in a limiting reagent situation.

In part 7 students were required to write equations to represent reactions illustrated by “before” and “after” diagrams. The first four problems in this section involve simple multiples of the coefficients used in the equation, whereas examples 5 – 8 represented chemical reactions in which one reagent was a limiting reagent. An example of the screens displayed in this component of the model is shown in Figure 10-6.

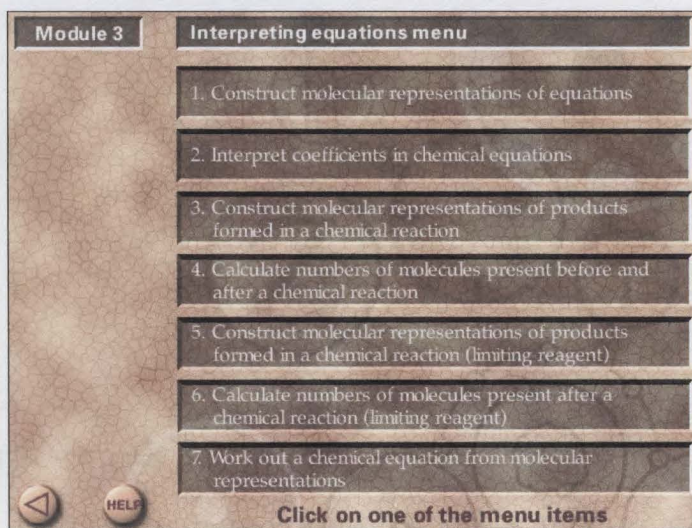


Figure 10-7 The computer screen menu bar within the third module.

## APPENDIX 2

### PRETEST / POSTTEST

#### Questions: Balancing and Interpreting Chemical Equations

Name: \_\_\_\_\_

Year: \_\_\_\_\_

School: \_\_\_\_\_

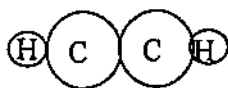
1. Explain what the following formulae represent. Your answer should include the number and types of atoms involved.

a)  $\text{NH}_3$

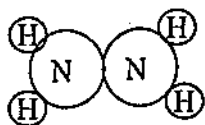
b)  $2\text{HCl}$

2. Write a formula for each of the following substances.

a)

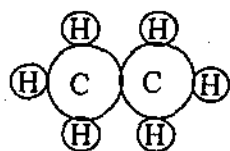


b)





c)



3. Draw a diagram to represent the following substances at the particulate level. Label each atom involved.

a)  $\text{NH}_3$

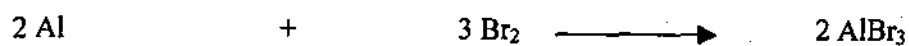
b)  $2\text{HCl}$

c)  $2\text{SO}_2$

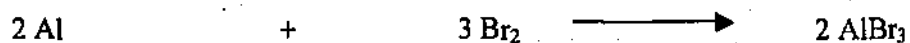
4. Balance the following equations.



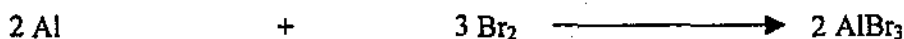
5. Explain what the following equations represent in terms of the numbers and types of particles involved.



6. Draw diagrams for the following equation to represent the reactant and product substances in the reaction, at the particulate level.

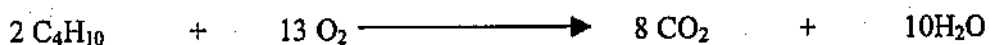


7. How many particles of Al are required to react with 3 particles of  $\text{Br}_2$ , in the following equation ?



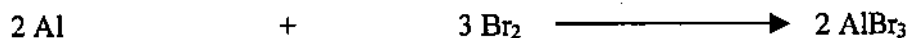
answer: \_\_\_\_\_

8. How many particles of  $C_4H_{10}$  are required to react with 13 particles of  $O_2$ , in the following equation ?



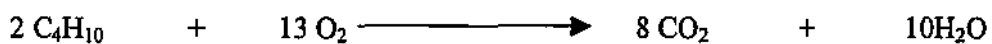
answer: \_\_\_\_\_

9. How many particles of  $AlBr_3$  are produced from the reaction of 4 particles of  $Al$ , in the following reaction ?



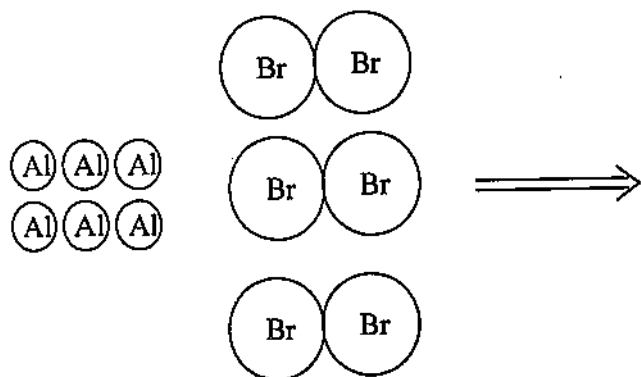
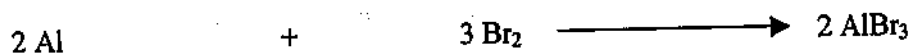
answer: \_\_\_\_\_

10. How many particles of  $\text{H}_2\text{O}$  are produced from the reaction of 10 particles of  $\text{C}_4\text{H}_{10}$ , in the following reaction ?



answer: \_\_\_\_\_

11. Draw a diagram to represent the products formed from the reaction of Al and Br<sub>2</sub> particles, which is represented by the following equation.



At the end of this reaction,

How many Al particles remain?

\_\_\_\_\_

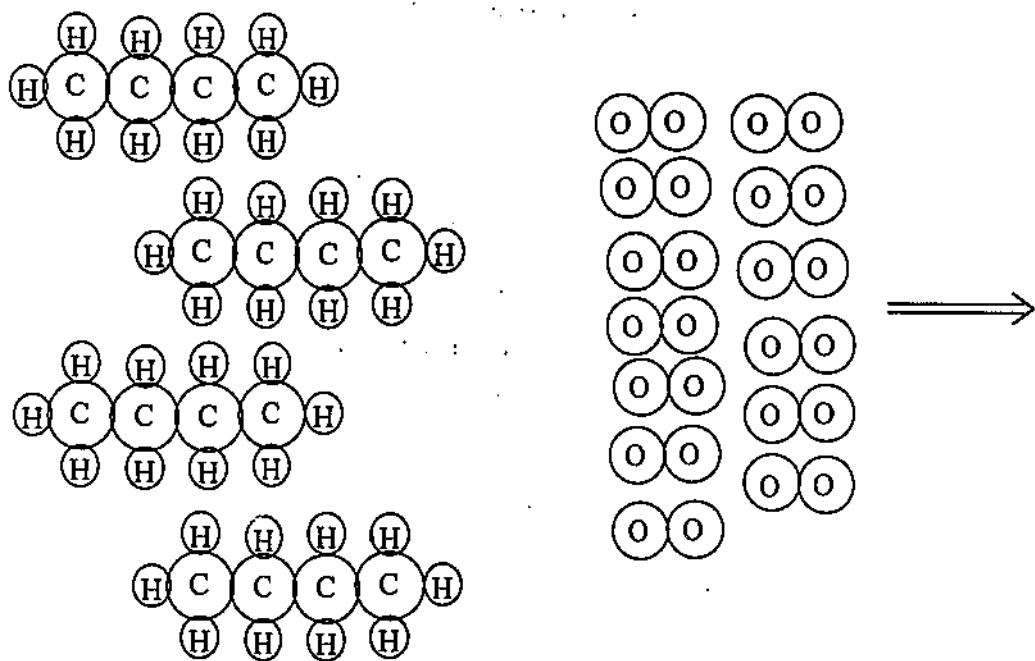
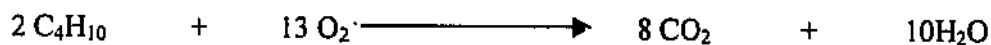
How many Br<sub>2</sub> particles remain?

\_\_\_\_\_

How many AlBr<sub>3</sub> particles are formed?

\_\_\_\_\_

12. Draw a diagram to represent the products formed from the reaction of  $\text{C}_4\text{H}_{10}$  and  $\text{O}_2$  particles, which is represented by the following equation.



At the end of this reaction,

How many  $\text{C}_4\text{H}_{10}$  particles remain?

\_\_\_\_\_

How many  $\text{O}_2$  particles remain?

\_\_\_\_\_

How many  $\text{CO}_2$  particles are formed?

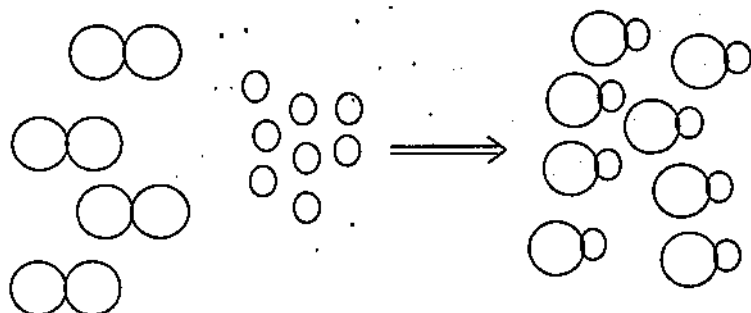
\_\_\_\_\_

How many  $\text{H}_2\text{O}$  particles are formed?

\_\_\_\_\_

13. Look at the reactions, that are represented by the following diagrams and answer the attached questions

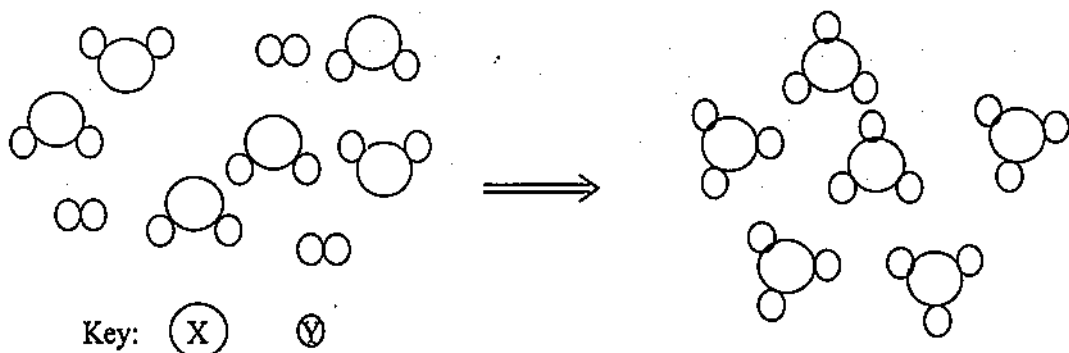
a.



Key:  $\bigcirc_X$   $\bigcirc_Y$

- How many different types of reactant particles are in this reaction? \_\_\_\_\_
- How many different types product particles are in this reaction? \_\_\_\_\_
- Write an equation that represents this reaction using appropriate symbols.

b.

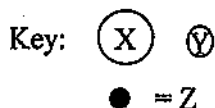
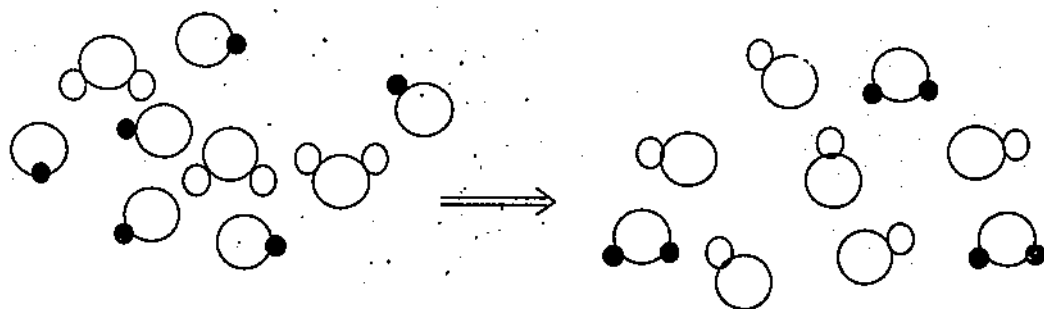


Key:  $\bigcirc_X$   $\bigcirc_Y$

- How many different types of reactant particles are in this reaction? \_\_\_\_\_
- How many different types product particles are in this reaction? \_\_\_\_\_
- Write an equation that represents this reaction using appropriate symbols.

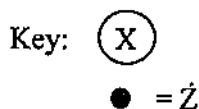
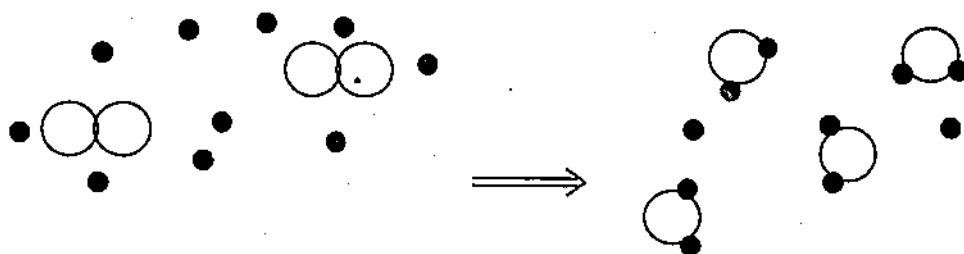


c.



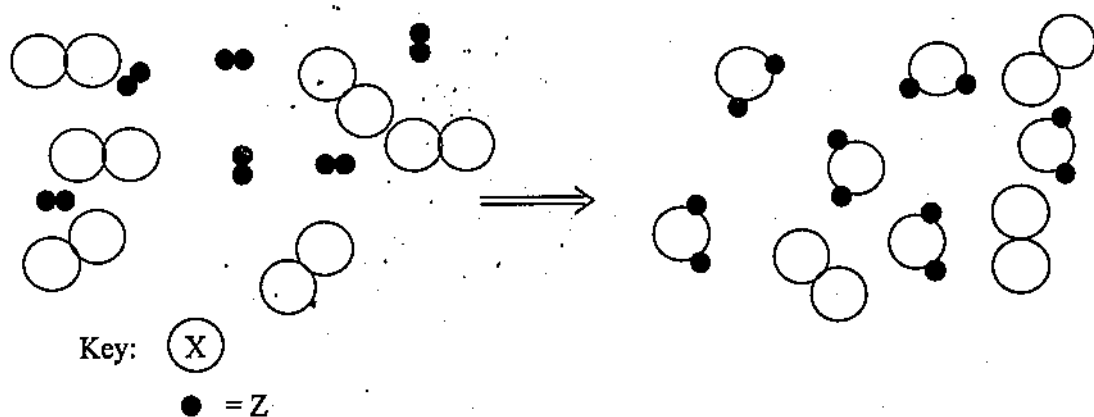
- (i) How many different types of reactant particles are in this reaction? \_\_\_\_\_
- (ii) How many different types product particles are in this reaction? \_\_\_\_\_
- (iv) Write an equation that represents this reaction using appropriate symbols. \_\_\_\_\_

d.



- (i) How many different types of reactant particles are in this reaction? \_\_\_\_\_
- (ii) How many different types product particles are in this reaction? \_\_\_\_\_
- (iii) Which chemical is not completely used up? \_\_\_\_\_
- (iv) How many of these unreacted particles remain? \_\_\_\_\_
- (v) Write an equation that represents this reaction using appropriate symbols. \_\_\_\_\_

e.



- (i) How many different types of reactant particles are in this reaction? \_\_\_\_\_
- (ii) How many different types product particles are in this reaction? \_\_\_\_\_
- (iii) Which chemical is not completely used up? \_\_\_\_\_
- (iv) How many of these unreacted particles remain? \_\_\_\_\_
- (vi) Write an equation that represents this reaction using appropriate symbols. \_\_\_\_\_

**END OF TEST**

**THANK YOU FOR YOUR ASSISTANCE**

## APPENDIX 3

### SCAFFOLDED GUIDES

#### Balancing and Interpreting Chemical Equations Work sheet 1

Use the following instructions and guides to assist you to understand how to balance and interpret chemical equations. When you feel that you have mastered the ideas and that you can complete the questions without these guides, ask your teacher for Worksheet 2.

1. Select a chemical reaction from the list in the Molecular Equation Module.
2. Watch the demonstration video.
3. Replay the video and note the following:
  - What are the names of the two reactants?

- Write the name of the products formed by the reaction?

4. Replay the video and note the following:
  - What colour is each of the reactants?

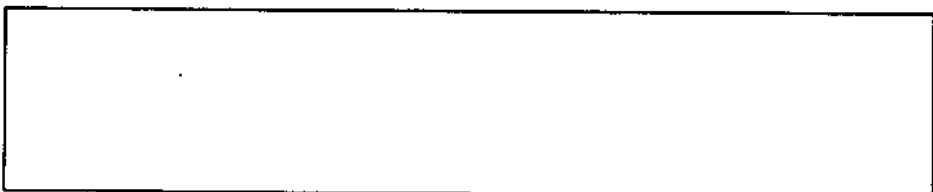
- Write colour is each of the products?



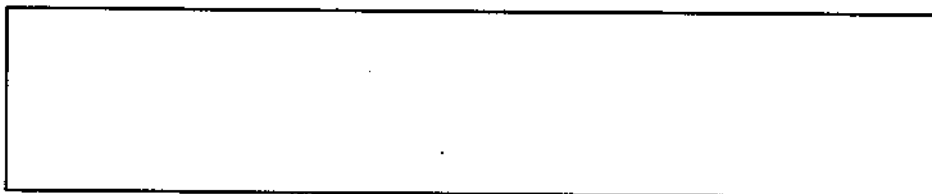
5. Watch the computer simulation of the reaction.

6. Replay the simulation and note the following:

- Draw a diagram to represent the structure of the reactant particles (note the relative sizes of particles).



- What colour are the models of each reactant particle?

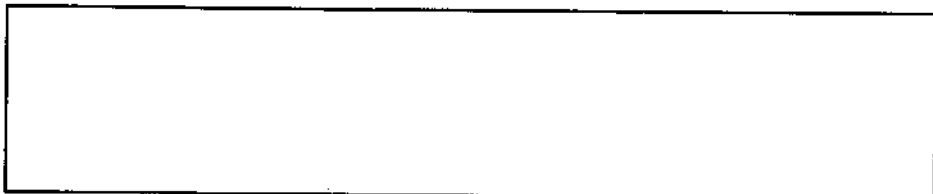


- Write a formula to represent each of the reactants



7. Replay the simulation and note the following:

- Draw a diagram to represent the structure of the product particles (note the relative sizes of particles).



- What colour are the models of each product particles?

- Write a formula to represent each of the products.

8. Replay the simulation and note the following:

- In the reaction that is shown, how many of each different type of reactant particles are needed in the reaction?

9. Replay the simulation and note the following:

- In the reaction that is shown, how many of each different type of product particles are formed in the reaction?

10. In order for this reaction to take place, what must the reactant particles do to each other?

11. Use the following guides to assist you to write the balanced chemical equation.  
When you have finished, enter your equation into the computer.

Working space:

→

- Look at question 6 on this worksheet – find the formula of each of the reactants.
- Write the formula of each reactant in the space on the left hand side of the arrow.
- Put a “plus” (+) sign between each of the reactants.
- Look at question 7 on this worksheet – find the formula of each of the reactants.
- Write the formula of each reactant in the space on the right hand side of the arrow.
- Put a “plus” (+) sign between each of the products
- In order to “balance” the equation you must indicate the number of each type of reactant that was used in the reaction and the number of each type of product formed in the reaction.
- Look at your answer to question 8 on this worksheet.
- Place the number of each reactant particles used in this reaction in front of its symbol in the chemical equation.
- Look at your answer to question 9 on this worksheet.
- Place the number of each product particles formed in this reaction in front of its symbol in the chemical equation.
- Use the following to check if you are right:

*Add up the number of each type of element on the reactant side of the equation, then add up the number of each type of element on the product side of the equation. You are correct if these numbers of each element type are the same on both sides of the equation. If it is not correct, return to question 6 and work through the steps again.*

**Balancing and Interpreting Chemical Equations**  
**Work sheet 2**

Use the following instructions and guides to assist you to understand how to balance and interpret chemical equations. When you feel that you have mastered the ideas and that you can complete the questions without these guides, ask your teacher for Worksheet 3.

1. Select a chemical reaction from the list in the Molecular Equation Module.
2. Watch the demonstration video.
3. Replay the video and note the following:
  - What are the names of the two reactants?

- Write the name of the products formed by the reaction?

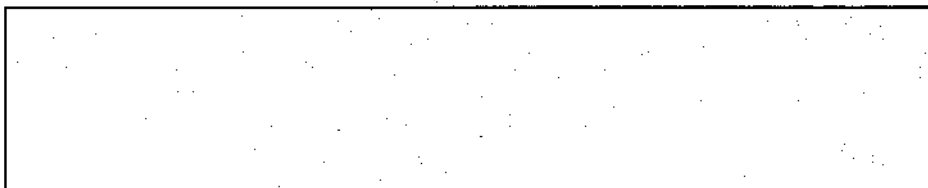
4. Replay the video and note the following:
  - What colour is each of the reactants?

- Write colour is each of the products?

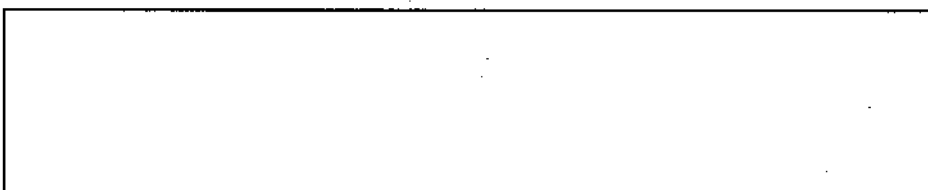
5. Watch the computer simulation of the reaction.

6. Replay the simulation and note the following:

- Draw a diagram to represent the structure of the reactant particles



- Write a formula to represent each of the reactants

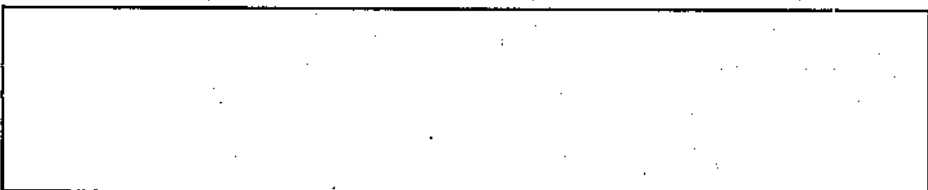


7. Replay the simulation and note the following:

- Draw a diagram to represent the structure of the product particles



- Write a formula to represent each of the products.





8. Replay the simulation and note the following:

- In the reaction that is shown, how many of each different type of reactant particles are needed in the reaction?

- In the reaction that is shown, how many of each different type of product particles are formed in the reaction?

9. Use the following guides to assist you to write the balanced chemical equation.  
When you have finished, enter your equation into the computer.

Working space:

→

- Write the formula of each reactant in the space on the left hand side of the arrow.
- Put a "plus" (+) sign between each of the reactants.
- Write the formula of each reactant in the space on the right hand side of the arrow.
- Put a "plus" (+) sign between each of the products

- In order to “balance” the equation you must indicate the number of each type of reactant that was used in the reaction and the number of each type of product formed in the reaction.

- Use the following to check if you are right:

Add up the number of each type of element on the reactant side of the equation, then add up the number of each type of element on the product side of the equation. You are correct if these numbers of each element type are the same on both sides of the equation.

**Balancing and Interpreting Chemical Equations**  
**Work sheet 3**

Use the following instructions and guides to assist you to understand how to balance and interpret chemical equations:

1. Select a chemical reaction from the list in the Molecular Equation Module.
2. Watch the demonstration video.
3. Replay the video and note the following:
  - What are the names of the two reactants?

- Write the name of the products formed by the reaction?

- What colour is each of the reactants?

- Write colour is each of the products?

4. Watch the computer simulation of the reaction.

- Write a formula to represent each of the reactants

- Write a formula to represent each of the products.

5. Use the following guides to assist you to write the balanced chemical equation.  
When you have finished, enter your equation into the computer.

Working space:

## **APPENDIX 4**

### **DEVELOPMENT OF GENERAL ASSERTIONS**

The General Assertions developed in Chapter 8 have been drawn from the individual assertions resulting from the analysis of the data, presented and discussed in Chapters 4, 5, 6 and 7. The individual assertions that support the General Assertions are illustrated on the following pages.

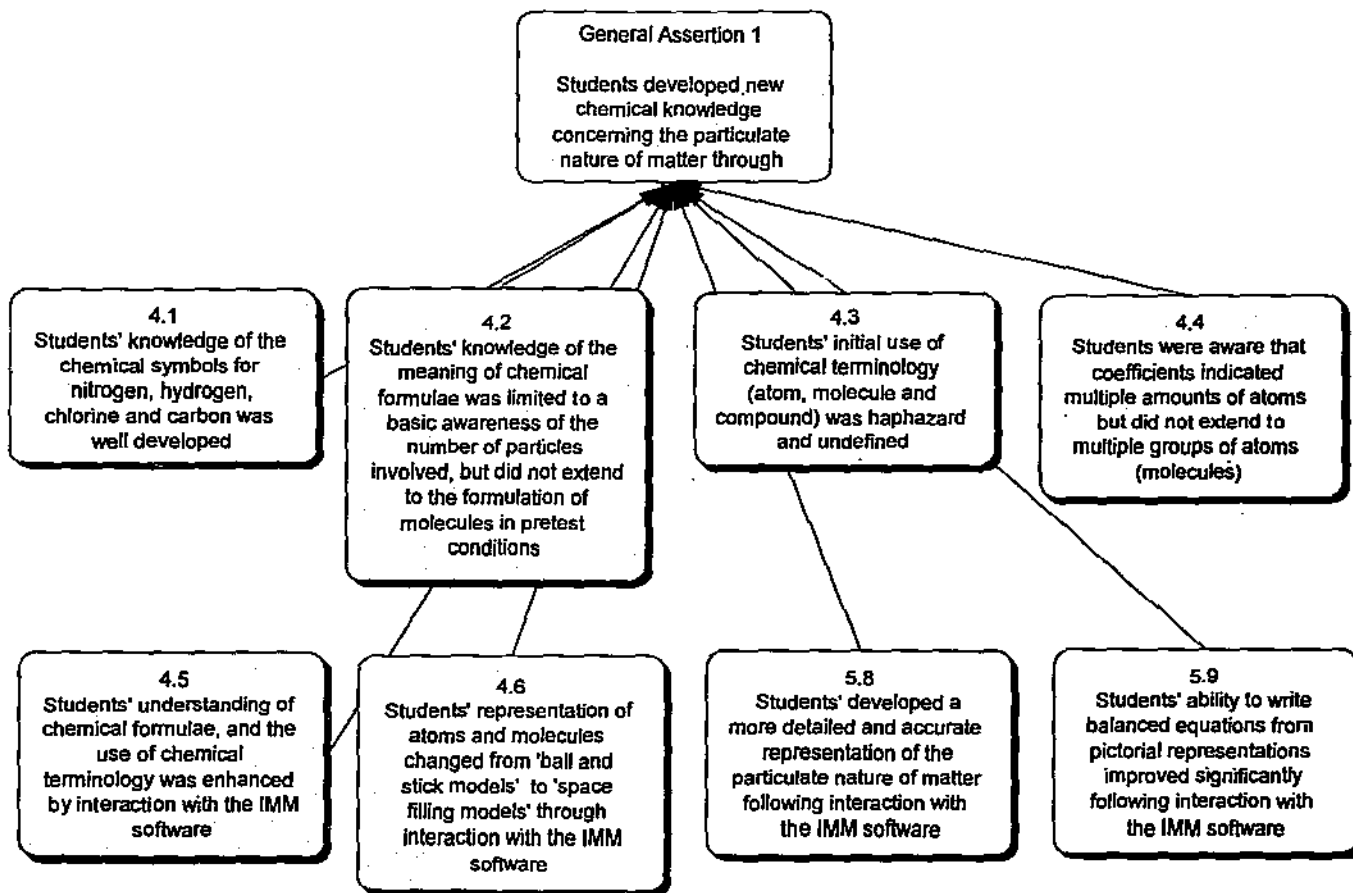


Figure 10-8 The development of General Assertion 1

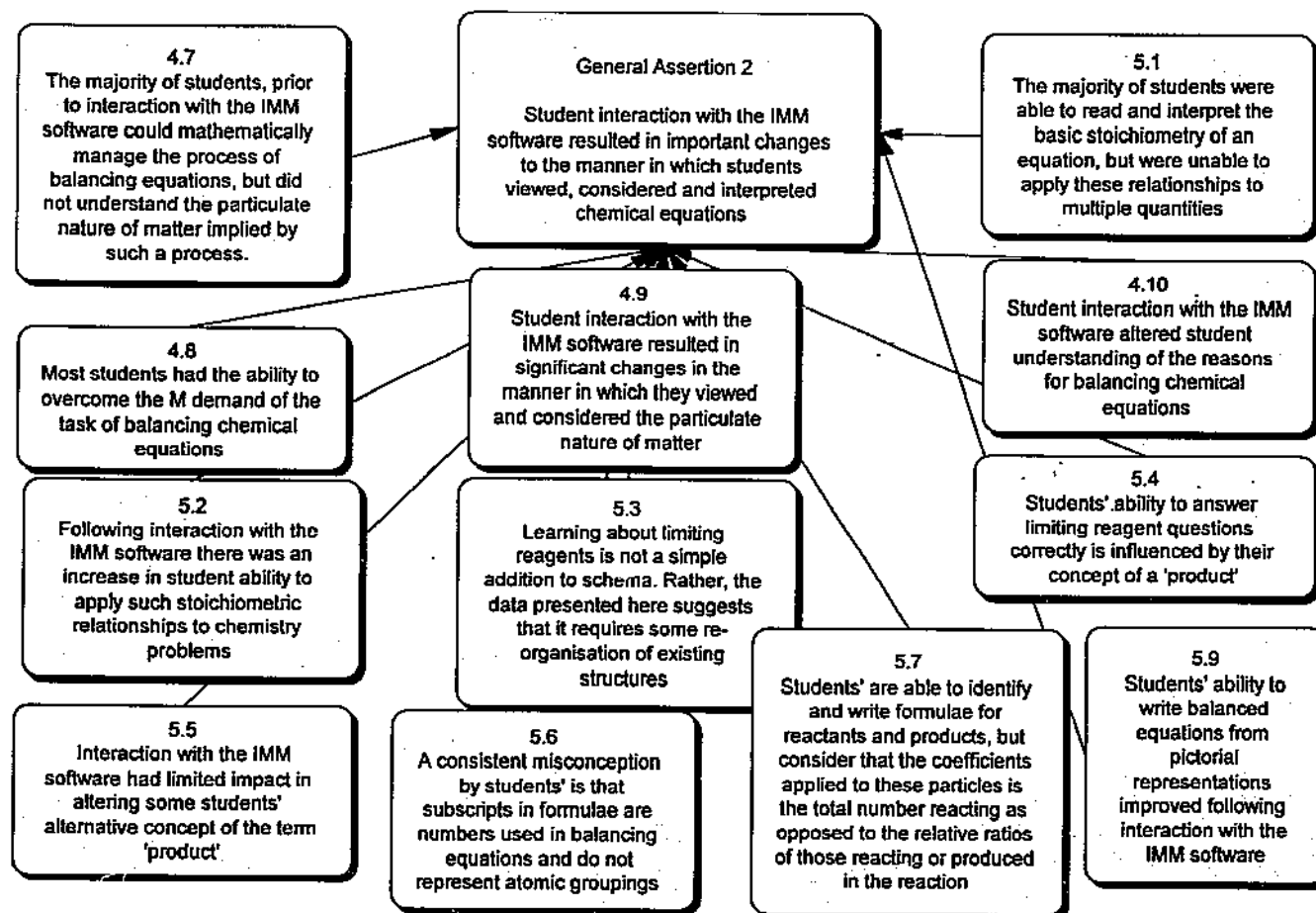


Figure 10-9 The development of General Assertion 2

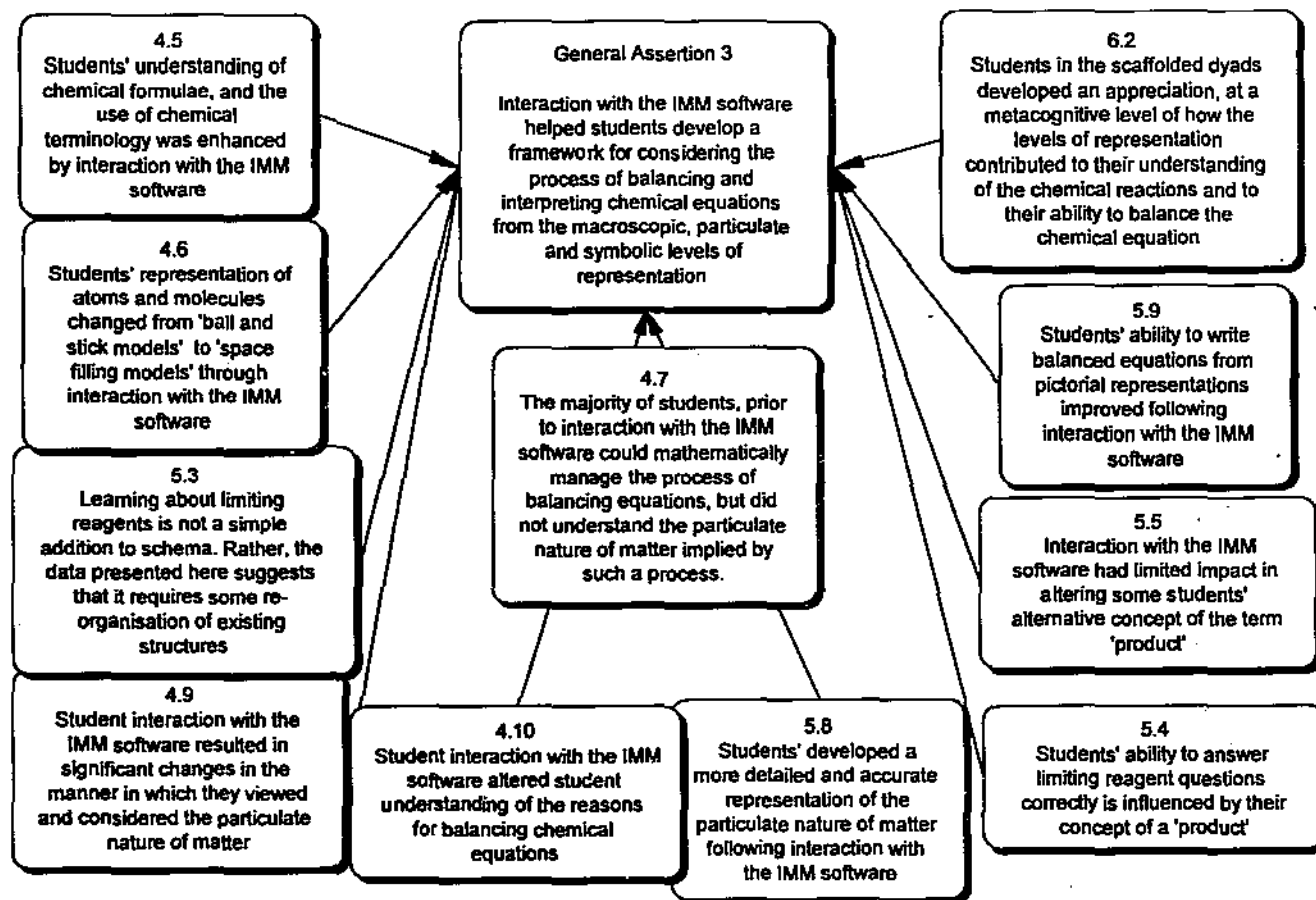


Figure 10-10 The development of General Assertion 3



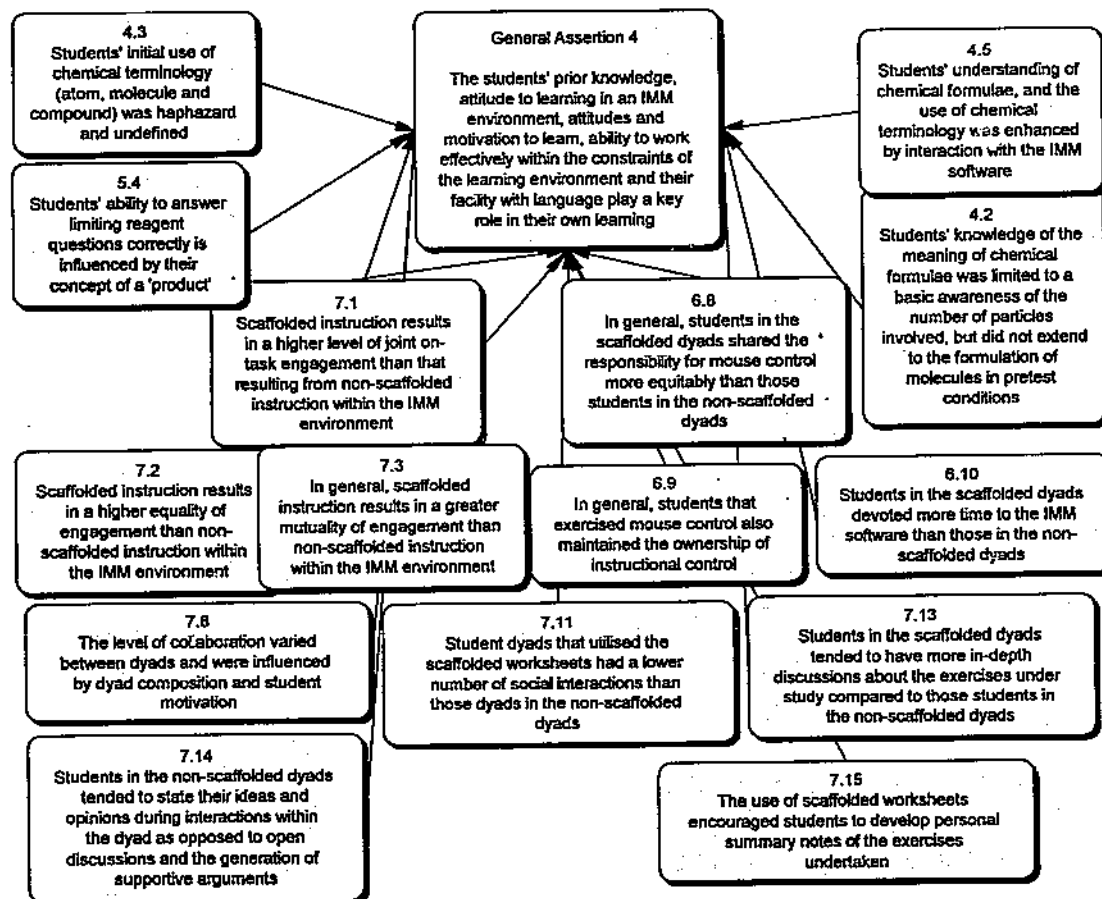


Figure 10-11 The development of General Assertion 4

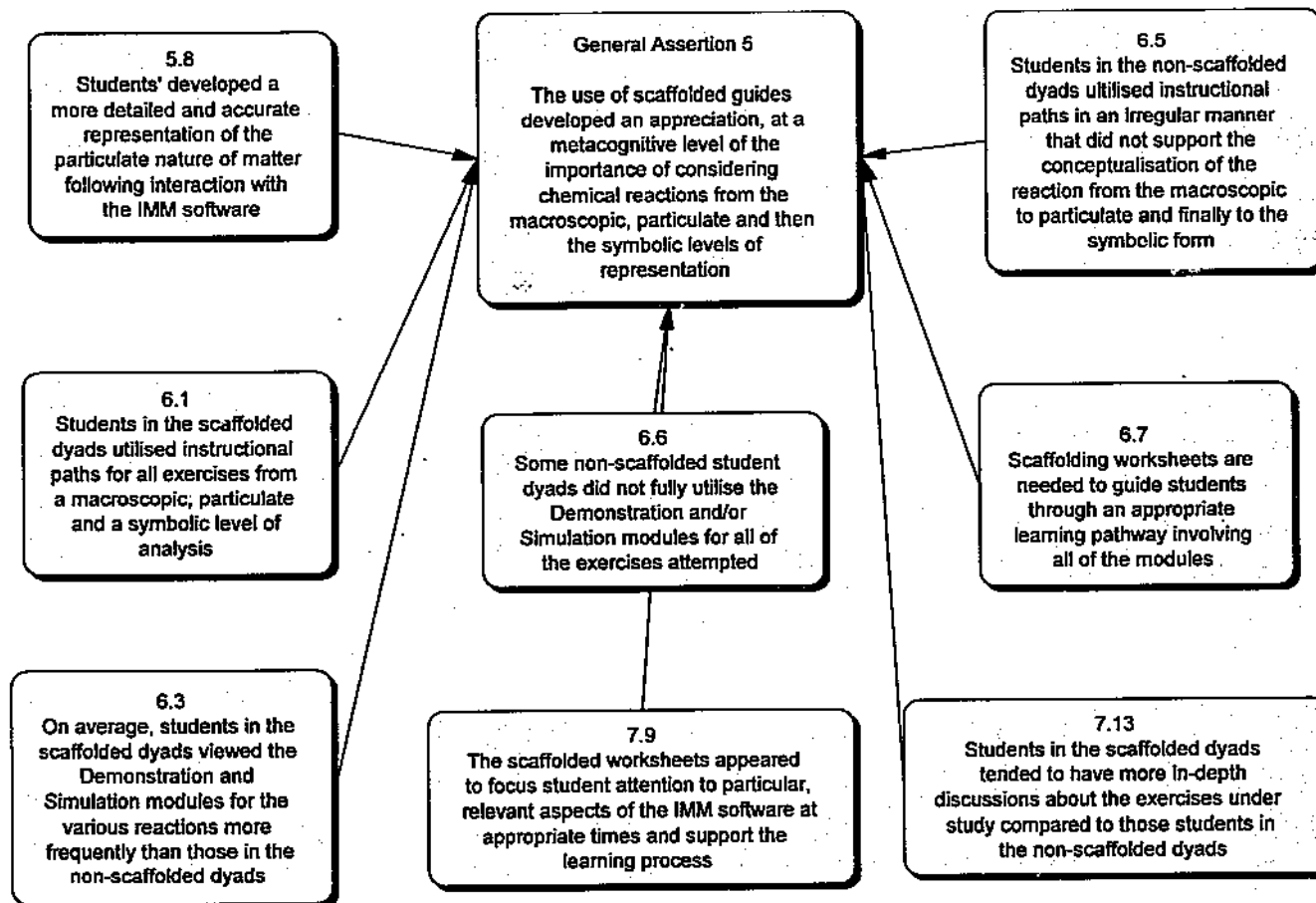


Figure 10-12 The development of General Assertion 5

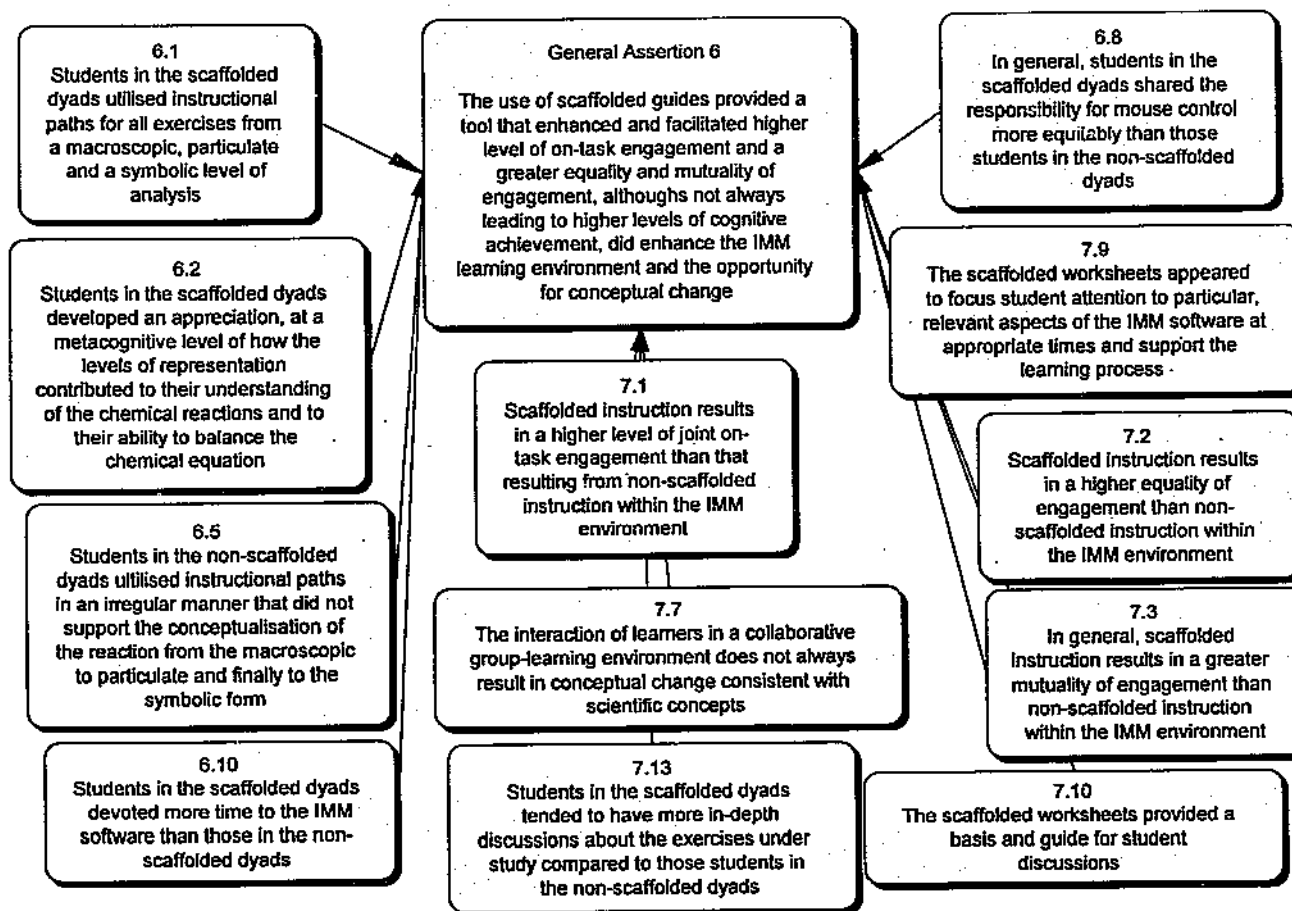


Figure 10-13 The development of General Assertion 6

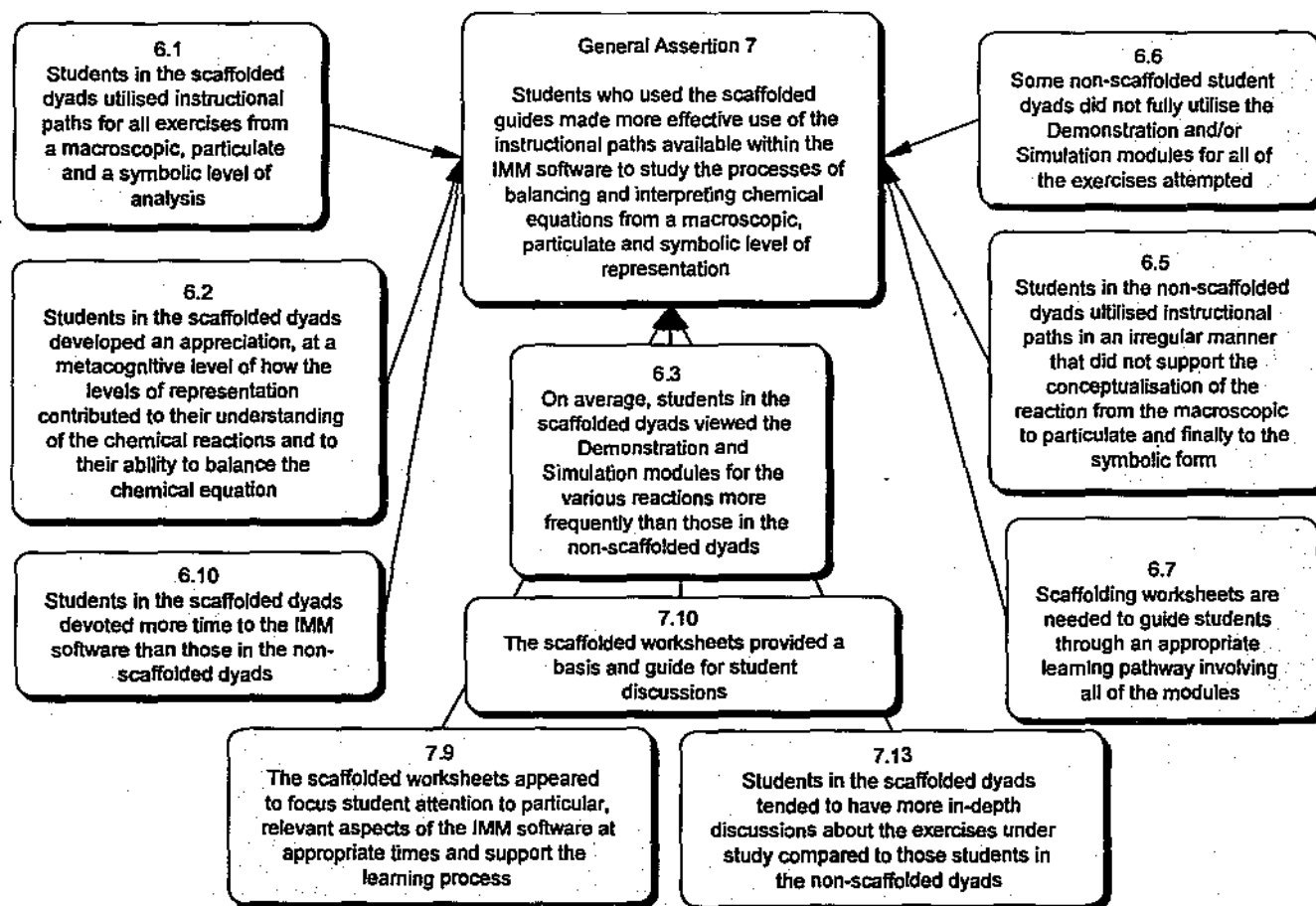
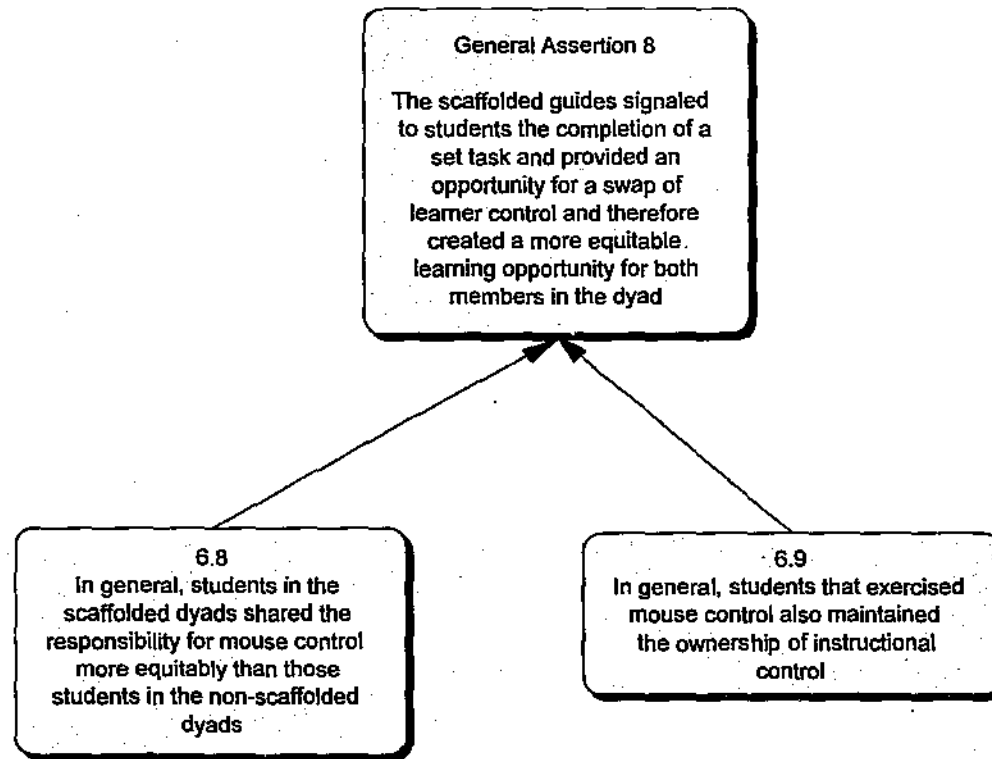


Figure 10-14 The development of General Assertion 7



*Figure 10-15 The development of General Assertion 8*

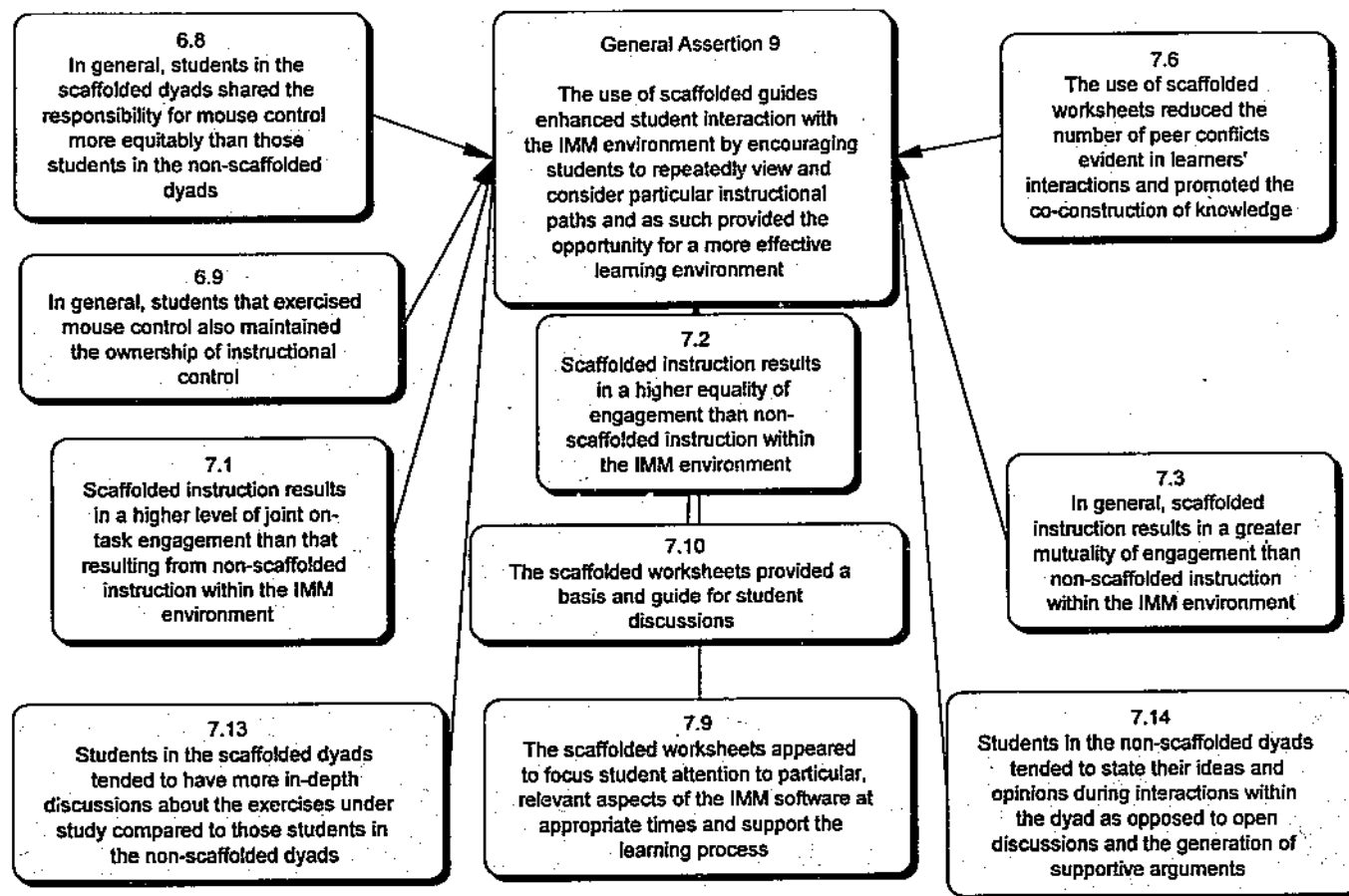


Figure 10-16 The development of General Assertion 9

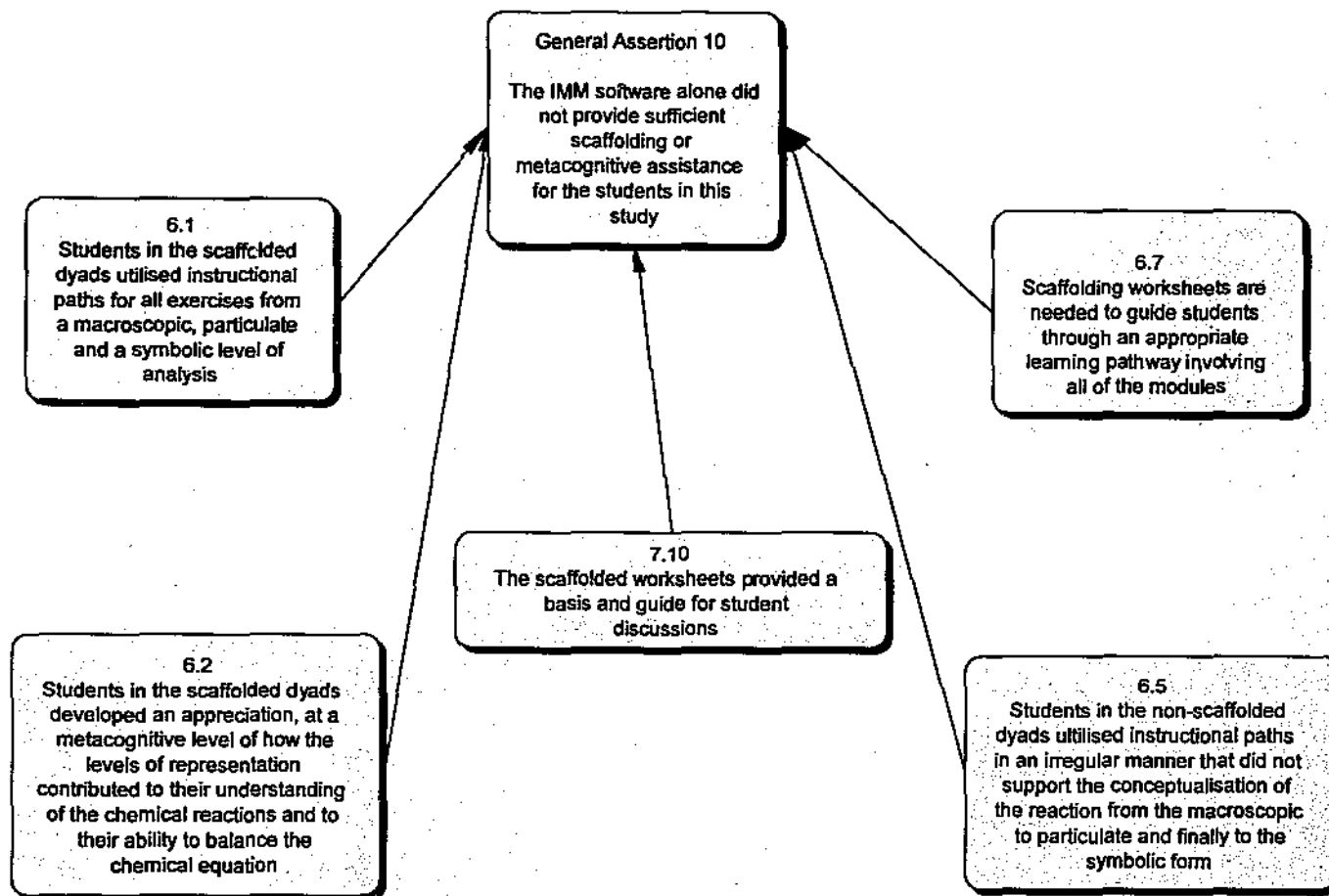


Figure 10-17 The development of General Assertion 10

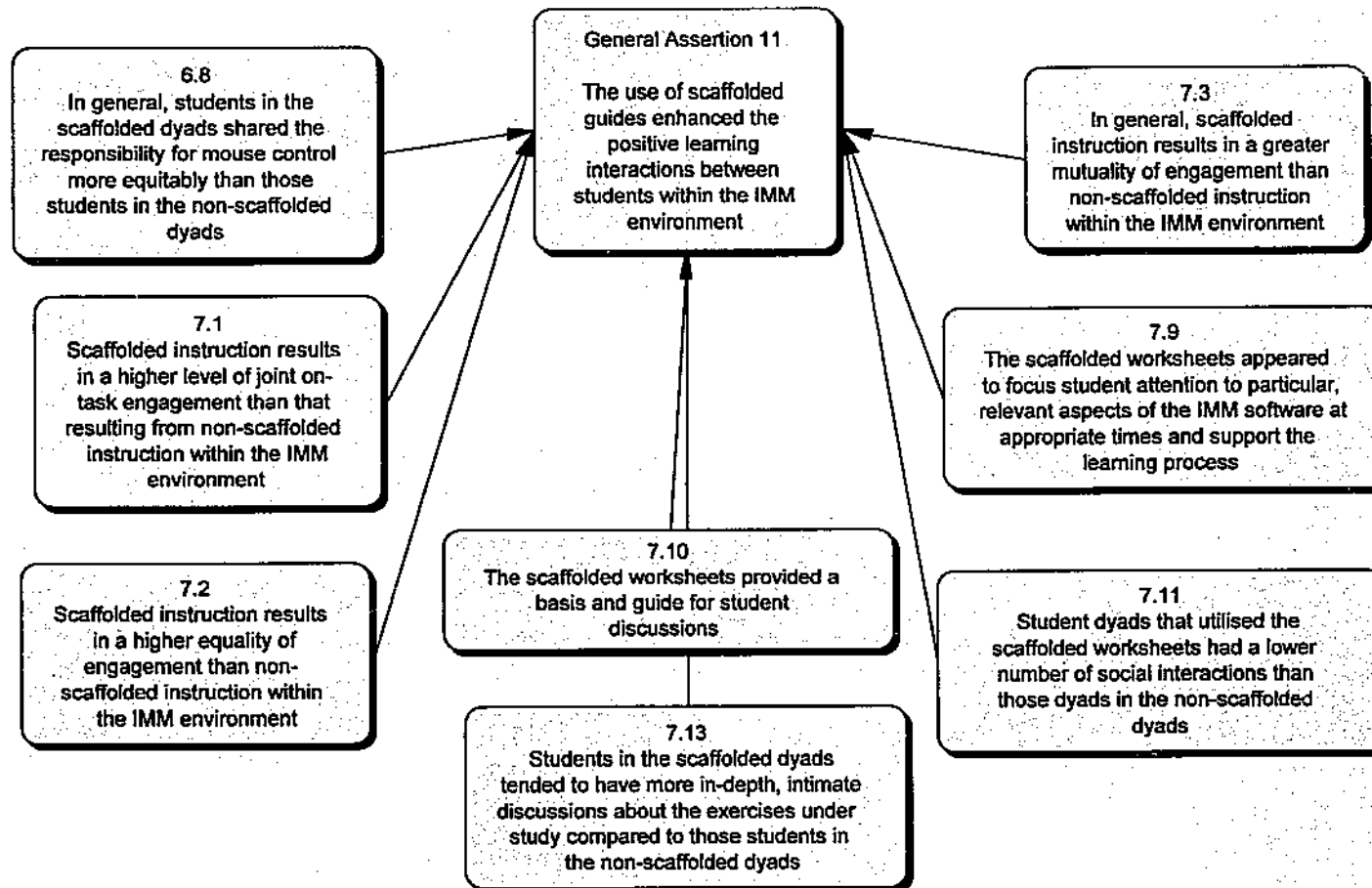
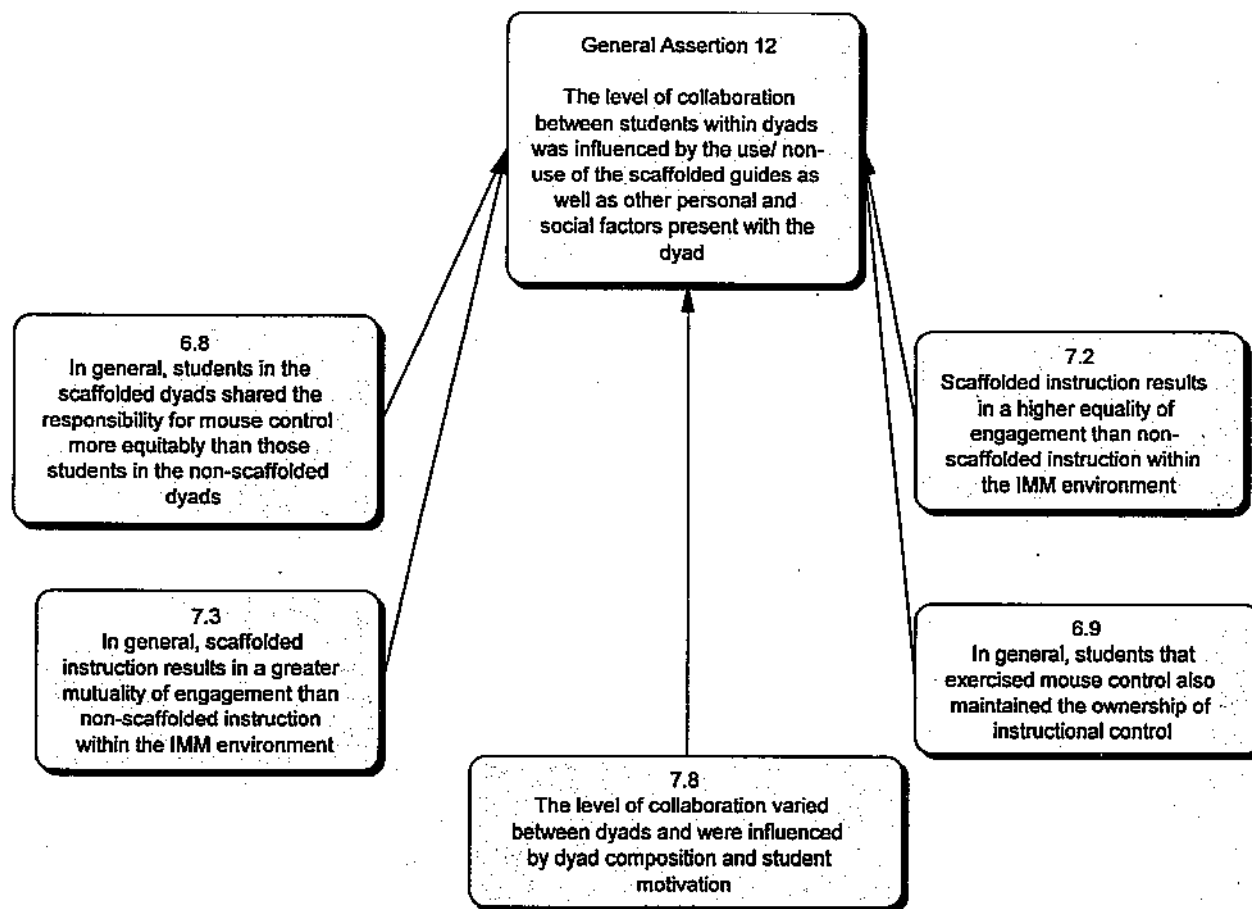


Figure 10-18 The development of General Assertion 11





*Figure 10-19 The development of General Assertion 12*

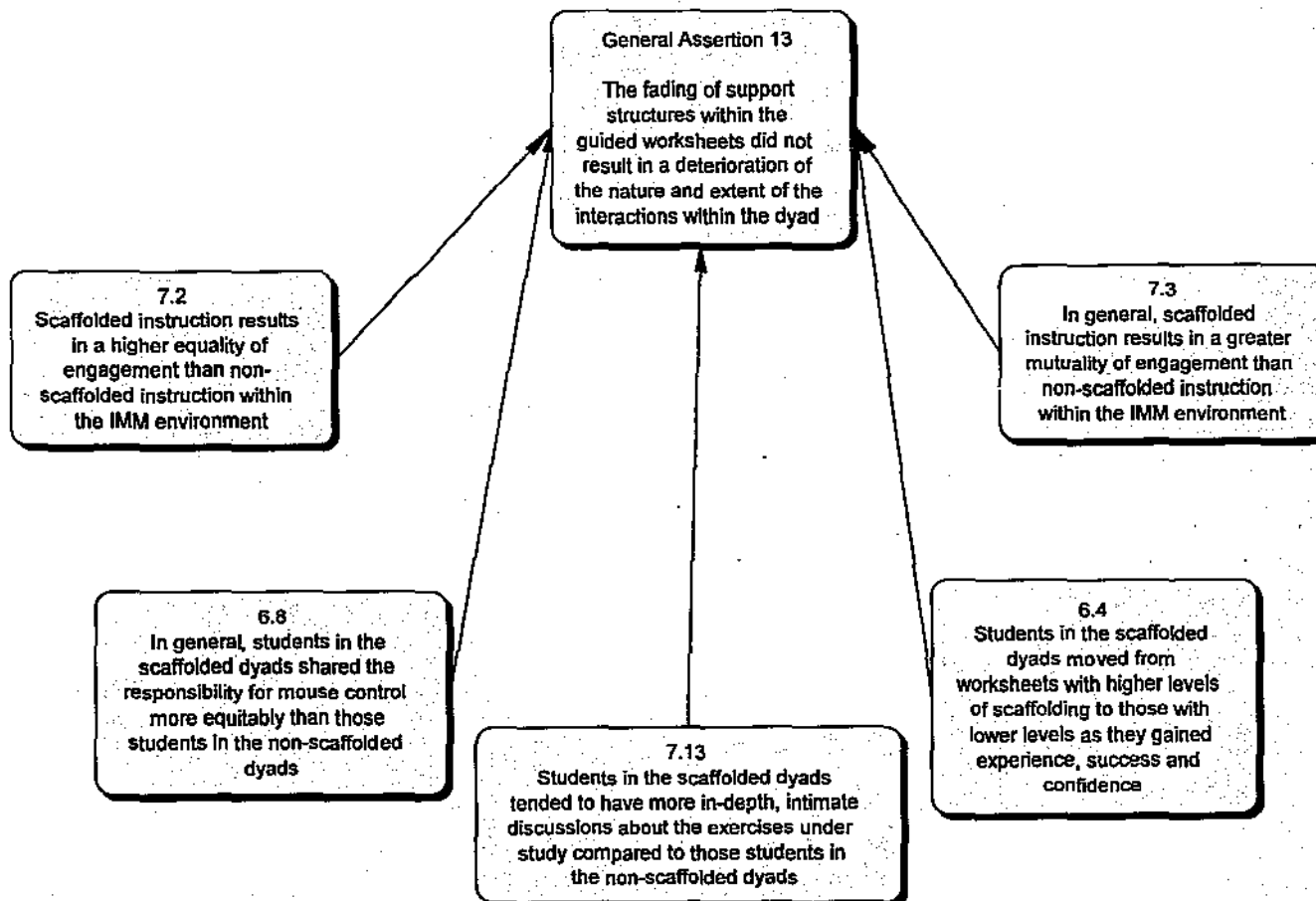


Figure 10-20 The development of General Assertion 13

## **APPENDIX 5**

### **DEVELOPMENT OF GENERAL CONCLUSIONS**

The General Conclusions developed in Chapter 8 have been drawn from the individual General Assertions resulting from the analysis of the data. The development of these conclusions are illustrated on the following pages.

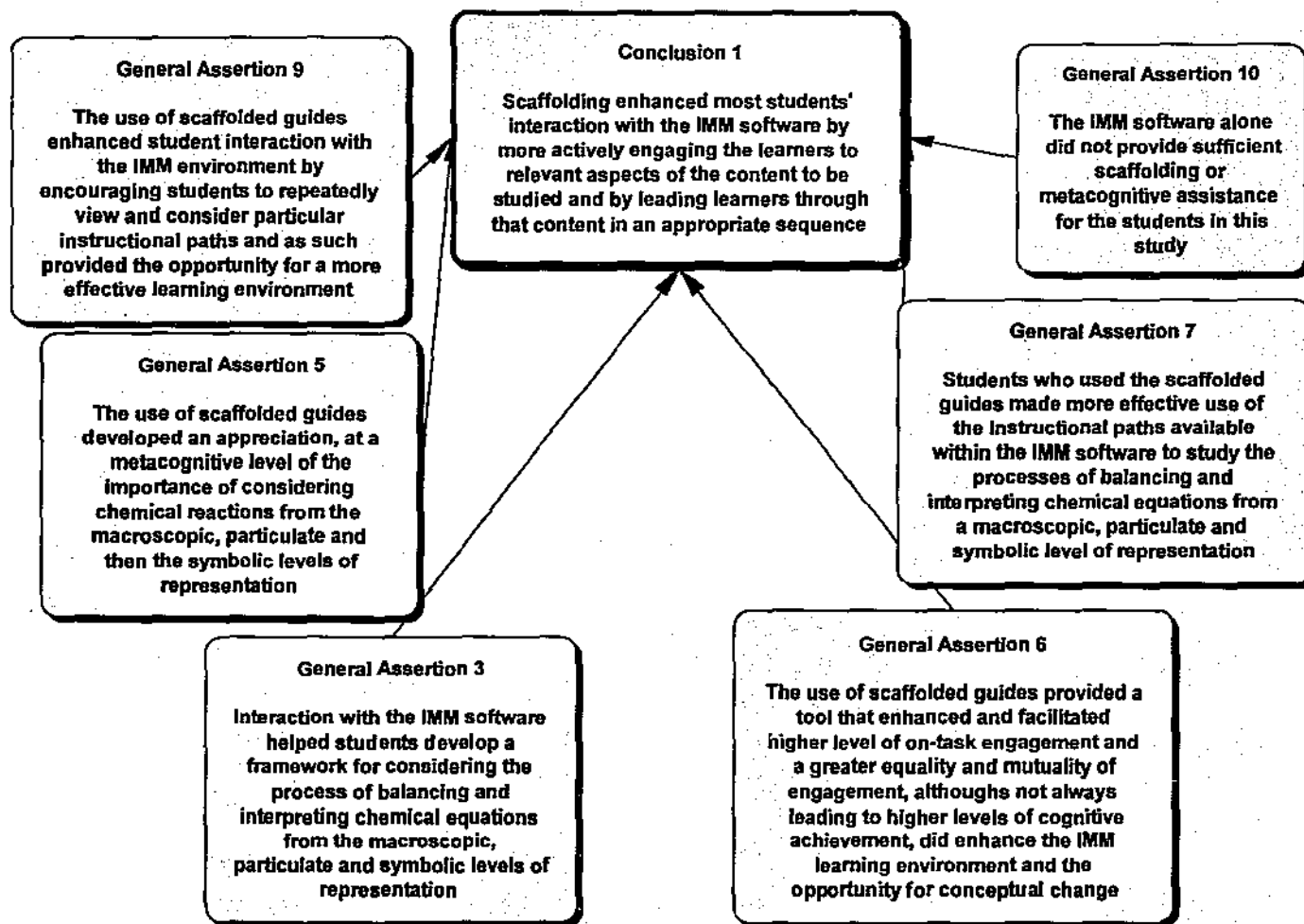
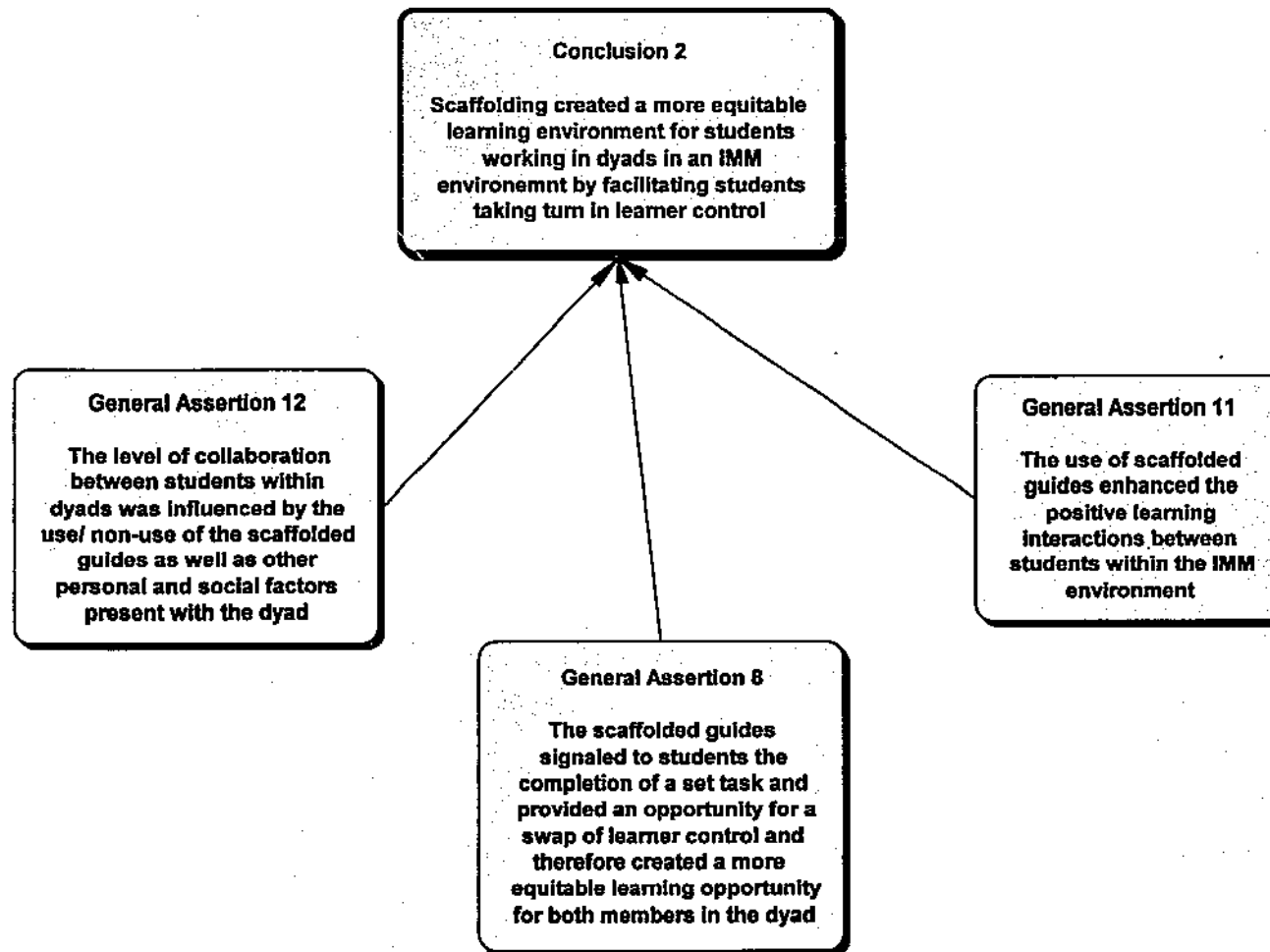


Figure 10-21. The development of Conclusion 1



*Figure 10-22 The development of Conclusion 2*

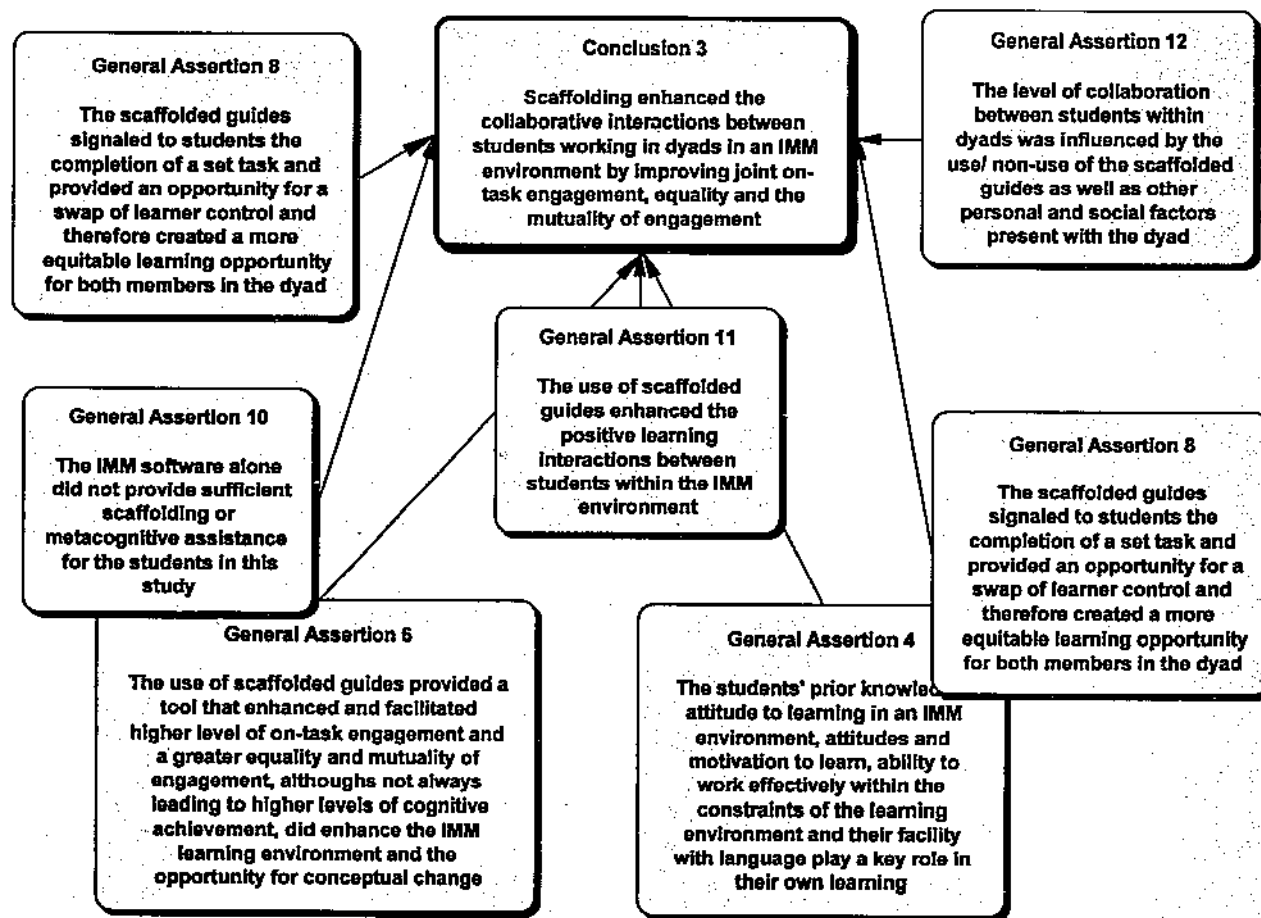


Figure 10-23 The development of Conclusion 3

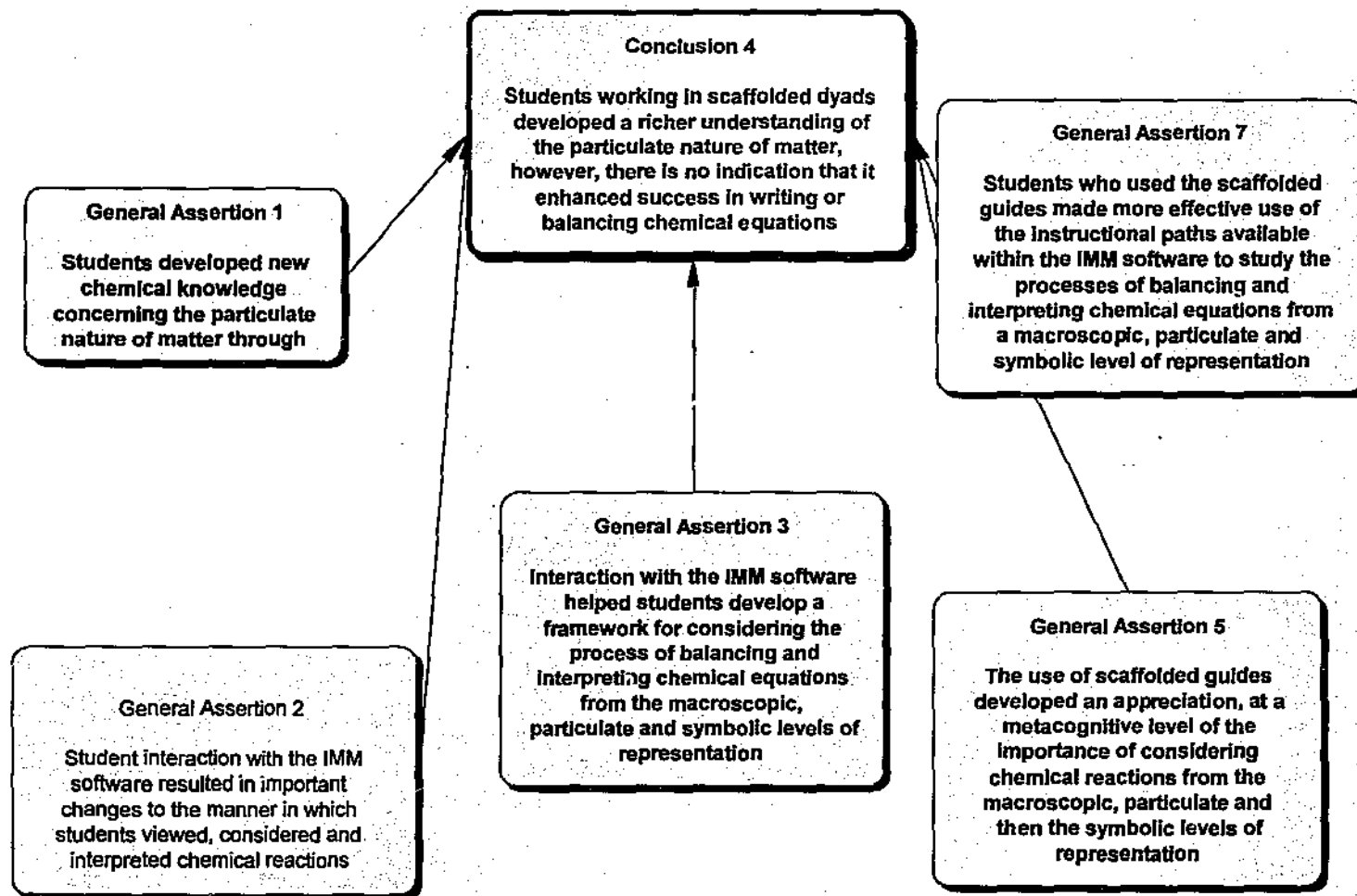


Figure 10-24 The development of Conclusion 4

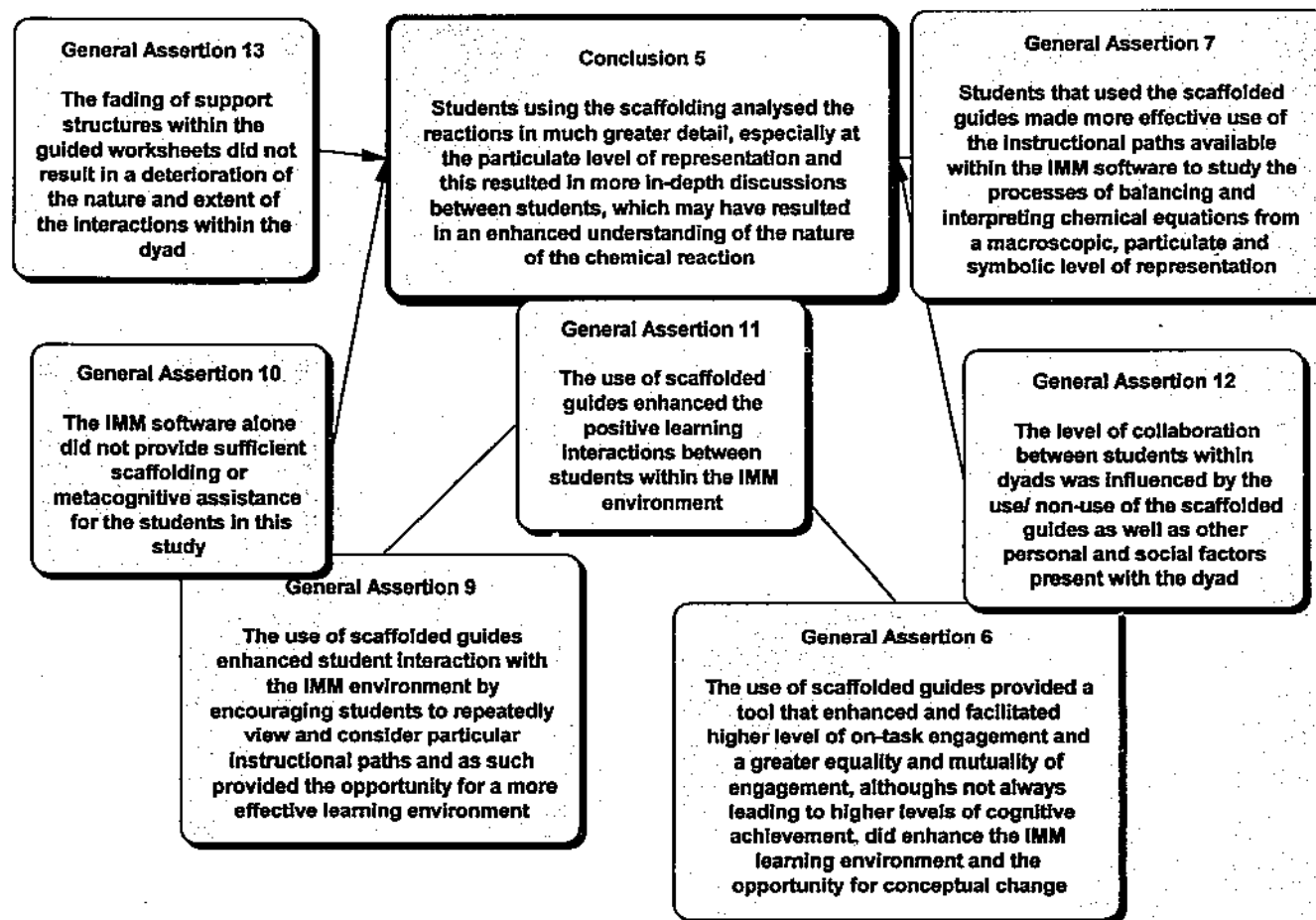


Figure 10-25 The development of Conclusion 5